EXPLORING AND VISUALIZING THE IMPACT OF MULTIPLE SHARED DISPLAYS ON COLLOCATED MEETING PRACTICES

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EXPLORING AND VISUALIZING THE IMPACT OF MULTIPLE SHARED DISPLAYS ON COLLOCATED MEETING PRACTICES

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PPT	Microsoft PowerPoint
GROUP	ACM Conference on Supporting Group Work
LCD	Liquid Crystal Display
GDSS	Group Decision Support System
InfoVis	Information Visualization

SUMMARY

A tremendous amount of information is produced in the world around us, both as a product of our daily lives and as artifacts of our everyday work. An emerging area of Human-Computer Interaction (HCI) focuses on helping individuals manage this flood of information. Prior research shows that multiple displays can improve an *individual* user's ability to deal with large amounts of information, but it is unclear whether these advantages extend for *teams* of people. This is particularly relevant as more employees are spending large portions of their workdays in meetings

My contribution to HCI research is empirical fieldwork and laboratory studies investigating how multiple shared displays improve aspects of teamwork. In particular, I present an insight-based evaluation method for analyzing how teams collaborate on a data-intensive sensemaking task. Using this method, I show how the presence and location of multiple shared displays impacted the meeting process with respect to performance, collaboration, and satisfaction. I also illustrate how multiple shared displays engaged team members who might not have otherwise contributed to the collaboration process.

Finally, I present Mimosa, a software tool developed to visualize large volumes of time series data. Mimosa combines aspects of information visualization with data analysis, facilitating a deep and iterative exploration of relationships within large datasets.

CHAPTER 1

INTRODUCTION

Information is produced in the world around us, both as a product of our daily lives and as artifacts of our everyday work. In fact, the volume of information generated in 2003 was estimated to be 1.5 billion gigabytes (Lyman, Varian et al. 2003). Knowledge workers contribute to this body of information through the generation of reports, notes, and email communications.

Active research within human-computer interaction (HCI) investigates and develops technologies to help individuals manage this flood of information, such as creating computer agents to intelligently filter information. Other researchers investigate and identify benefits of increased screen real estate, in both singular large displays or multiple smaller displays. Additional screen real estate affords individual users more space to display multiple software applications simultaneously. Researchers have demonstrated benefits of more screen real estate in terms of task performance, organization of information, and visibility of applications at a workstation (Grudin 2001; Czerwinski, Smith et al. 2003). Also, multiple monitors are becoming increasingly common in everyday working situations, not just in research labs (Kang and Stasko 2008). Computer manufacturers such as Apple and Dell currently sell large displays up to 30" diagonal in size and also sell computer systems that natively support multiple monitor configurations (Apple 2009; Dell 2009)

HCI multiple monitor research typically focuses on using displays at individual workstations, however, research from the business community indicates that knowledge workers spend up to half their workday away from their workstations in meetings (Davenport 2005). In addition, management and business community research indicates a shift within companies towards flat employment hierarchies utilizing self-organizing

Figure 1: Conference room at a US-based software company.

teams. (Owens 2000). It is therefore not surprising that many workers are issued laptop computers to promote portability, allowing workers instant access to information via wireless Internet.

Even though workers are spending an increasing amount of time collaborating and sharing information, multiple shared displays are not commonly found in meeting rooms, where individuals are spending longer periods of time. Several research labs created advanced meeting space systems consisting of multiple displays, devices, and software to promote collaboration (e.g. (Streitz, Geissler et al. 1999; Johanson, Fox et al. 2002)). However, as illustrated in Figure 1, many existing conference rooms outside of research labs are more simplistic, typically having one shared display such as a projector or large LCD, table and chairs, and a whiteboard.

This raises the question, do the advantages of multiple monitors for individual users extend to a group collaborating within a meeting space? If so, what are the barriers and challenges regarding real-world adoption? Furthermore, would an increased amount of shared displays change *how* groups collaborate?

In general, meeting spaces represent a challenging domain for technology designers. Meeting spaces are a complex, heterogeneous ecology of people, their motivation for collaborating, presentation and availability of information, and the presence of technology. Since collaboration is increasingly common within corporate and academic organizations, researchers must investigate technology innovations that may boost productivity without substantially increasing costs. We hypothesize that multiple shared displays can improve collaboration within meeting environment by allowing more information to be shared.

The goal of this thesis is to understand how multiple displays, in different meeting environments, influence the work practices of collocated individuals. This thesis provides insight into the costs versus benefits tradeoff of incorporating multiple shared displays in meeting environments, thus providing insight into the challenges of traversing the boundary between research and real world adoption.

1.1 Definitions and Clarification

1.1.1 Large Displays

The term *large display* can refer to both physical size of a display as well as the resolution of the device. For example, a typical physically large display may have a viewable area measuring 30 inches or more diagonally.

A high-resolution device may also be considered a large display. For example, a 17-inch flat-panel monitor may have a native resolution of 1680x1050 or 1920x1200.

The latter resolution provides approximately 30% more pixels in the same amount of space, allowing for more content to be visible.

Likewise, a physically large display may also be high-resolution. For example, a 40” LCD television may have a native resolution of 1366x768 or 1080x1024. For the intents of this dissertation, we narrow the definition of a large display to one that is physically large and has a resolution that makes the content viewable for a majority of people present in the collaborative space.

1.1.2 Shared Displays

The term *shared displays* is quite broad and encompasses many configurations. The term *large shared display* is one in which the display is physically large enough to be

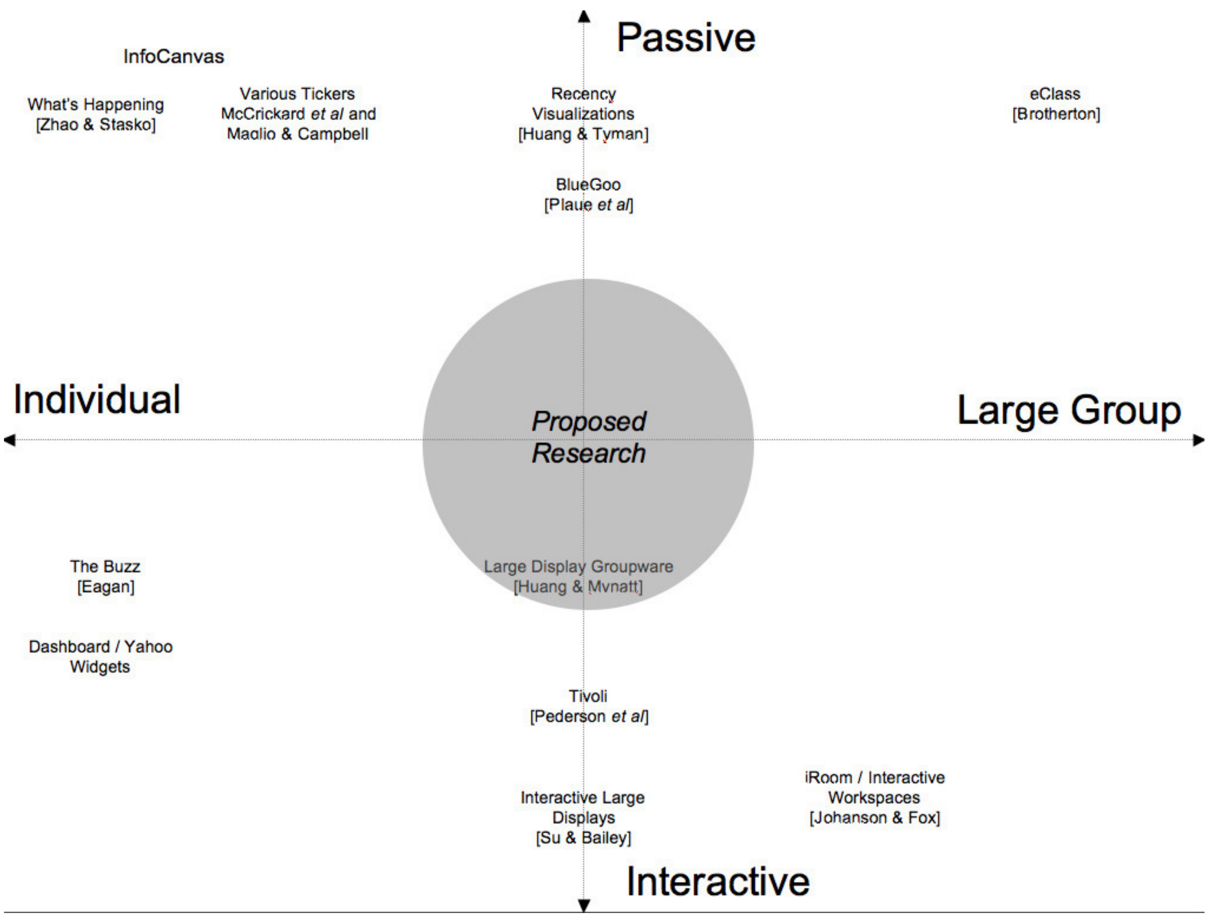


Figure 2: Taxonomy of shared display research space.

visible to multiple participants in a collocated setting. Typically, a user connects a personal or room-based computing device to a shared display. Shared displays can also exist in digital or analog form factors. Examples of digital shared displays include projectors and large LCDs. Examples of analog shared displays include whiteboards and poster boards.

Other shared displays may exist in a collocated meeting environment. For example, two individuals seated next to each other may jointly look at one laptop computer. In this situation, the single laptop acts as a shared display.

Figure 2 illustrates a research space taxonomy involving shared displays. The use of *shared displays* within this dissertation refers to a digital display that supports passive and interactive use. For example, a shared display may be used as a passive conveyor of information such as a meeting agenda or real-time stock updates. Conversely, individuals can use the shared display to actively create an artifact such as a list of design requirements.

1.1.3 Collocated Meeting

A collocated meeting is when individuals are physically present within the meeting space. With the advent of globalization, many corporations maintain communication with other divisions, suppliers, and manufacturing plants throughout the world. Conference calls and videoconferencing are often used to communicate with these outside entities in real-time.

In this dissertation, we focus on meeting spaces primarily supporting collocated work amongst two or more individuals, but no more than 10. We are not exploring systems designed to support larger crowds, such as classroom support tools. Many meeting spaces also are equipped for mixed presence meetings, but we focus on situations where the majority of meeting participants are physically within the same room.

1.1.4 Collaborative Spaces

Collaboration can occur in many places including traditional conference rooms, around the office water cooler, near shared printers, at a worker's individual workstation, or even in the hallway. To narrow the scope of this dissertation, we focus on dedicated meeting spaces commonly known as *conference rooms*. Note that researchers often will interchange the the terms *meeting spaces* and *conference rooms*.

1.2 Purpose of Research and Thesis Statement

As with most human-computer interaction research, this dissertation spans several academic disciplines. At one level, this research requires understanding existing meeting and collaborative processes. The Management Information Science research community has significantly researched the meeting process phenomena and lists elements of "good" meeting practices. For example, a good meeting environment supports (Wolf 1994):

- encouraging the expression of viewpoints, specifically inviting individuals who have not spoken much to voice their opinions
- the balance of control amongst individuals
- meeting closure through review and planning of future measures

HCI researchers typically focus on developing technological innovation to enhance collaboration by creating new interaction techniques and software frameworks to support information sharing. Many HCI research projects are long-term technological visions and may involve using maturing technology.

The work presented in this dissertation bridges the gap between the here-and-now research of the Management Information Science community regarding meeting practices and the long-range futuristic technological innovations developed by HCI researchers. We studied the effects of *the presence of* multiple shared displays on meeting practices in authentic and laboratory settings. We also visualized the types of activities occurring during collaboration to better understand the relationships between people, information, technology, and shared displays. We were not concerned with developing novel new interaction techniques or developing sophisticated technological infrastructure. Rather, our primary goal was to investigate how multiple shared displays influenced productivity and collaboration occurring in meeting rooms.

Our thesis statement is:

> *Multiple shared displays showing augmenting information in a collocated meeting environment can A) result in same or improved collaboration and communication amongst meeting participants, and B) result in same or improved satisfaction with the meeting process.*

To address this thesis statement, we collected and analyzed a significant amount of quantitative and qualitative data from two longitudinal field studies observing meeting practices before and after a second shared display was placed into each space. We also investigated employees' attitudes towards technology usage within meeting rooms, recognizing that devices are needed provide content to the shared displays. Thus, it was critical to learn how and when individuals used devices such as laptops while collaborating using shared displays.

In addition, we collected and analyzed data from a controlled laboratory evaluation exploring the impact of the presence and placement of multiple shared displays. To understand the types of activities that occur during collaboration with multiple shared displays, we logged low-level activities and interactions occurring during the meetings, and subsequently developed a visualization tool, Mimosa, to create graphical representations to reconstruct these low-level activities and explore relationships between them.

1.3 Research Contributions

Our research provides four main contributions:

- The identification of conditions when multiple shared displays impacted how teams collaborated, and the identification of conditions when multiple shared displays afforded opportunities to engage more passive team members.
- The design and implementation of an insight-based evaluation method to evaluate teams performing sensemaking tasks. Using this method, we show that the number of insights made by a team is positively correlated, in a nonlinear relationship, with the number of key facts obtained.
- The design and implementation of a visual analytical tool, Mimosa, for investigating time-series data.
- The identification of social aspects of meetings correlating to routines associated with shared display usage during meetings.

This work describes situations in which multiple shared displays were frequently used by meeting attendees, who subjectively reported benefits to the collaboration process. We also report situations in which the multiple shared displays were not adopted or used by meeting attendees. In addition, our research indicates that multiple shared displays influenced how groups collaborated on a sensemaking task. Organizations, especially within research and development arms, are constantly looking for methods to improve the creative process of individuals. Thus, we offer evidence of how multiple shared displays, as deployed in our studies, can augment existing collaborative processes.

1.4 Overview of Thesis

In this dissertation, we advance the knowledge of the technical and social processes associated with shared displays in meeting rooms. Our plan of study required extensive fieldwork investigating existing routines and practices surrounding technology usage within meetings to identify and isolate opportunities for enhancement via shared displays. We identified situations in which multiple shared displays enriched collaboration within meeting rooms and further evaluate this configuration under a controlled laboratory study.

Chapter 2 provides the background for this dissertation by describing existing work in collaborative environments, technologies developed for meeting usage, organizational behavior and trends, display placement, and the conflicting successes and failures of technologies within meeting spaces. We also describe several cognitive theories that model human behavior and attention spans within collaborative environments.

In Chapter 3, we describe the results of the two field studies observing populations at two companies during their day-to-day usage of meeting rooms, placing specific emphasis on investigating which devices are brought into meetings and actively used as well as when shared displays were used. In particular, we identify two activities occurring during meetings, namely sensemaking and peripheral information monitoring, that benefit from the presence of multiple shared displays. We also provide evidence that how users connect to shared displays or use technology during meetings is impacted not only by technology design, but by the social routines occurring during the meeting process.

We describe the design and implementation of a controlled laboratory study in Chapter 4, designed to further explore how the presence and location of multiple shared displays impacts the meeting process of groups performing a sensemaking task. In particular, we establish metrics to evaluate the meeting process along dimensions of performance, collaboration, and satisfaction with the meeting process.

The laboratory study method was designed to yield a large amount of data in the form of surveys, interviews, and low-level logged data of activities associated with the collaboration process, such as who was speaking, gesturing, or using a shared display at a particular moment in time. In Chapter 5, we describe the design and implementation of a visual analytic tool, Mimosa, to visualize the low-level activities exhibited by teams collaborating during the laboratory study. Visual analytics is an emerging research field, combining elements of information visualization and data analysis within software tools.

In Chapter 6, we describe the results of our controlled laboratory study. We provide our analysis in terms of descriptive and inferential statistics, qualitative methods, and also used Mimosa to explore the relationships between individuals, information and display usage.

Finally, we summarize the results of the fieldwork and experimental studies in Chapter 7. We also outline contributions from this dissertation as well as discuss future research directions.

CHAPTER 2

BACKGROUND

Meetings represent an ecology of individuals, technologies, and information. In this chapter, we examine previous work in each of the primary topic areas of this dissertation, as illustrated in Figure 3. Broadly stated, related work includes investigating performance benefits and usage habits of multiple displays on individual work; technology usage during meetings; organizational behavior and trends; and technologies

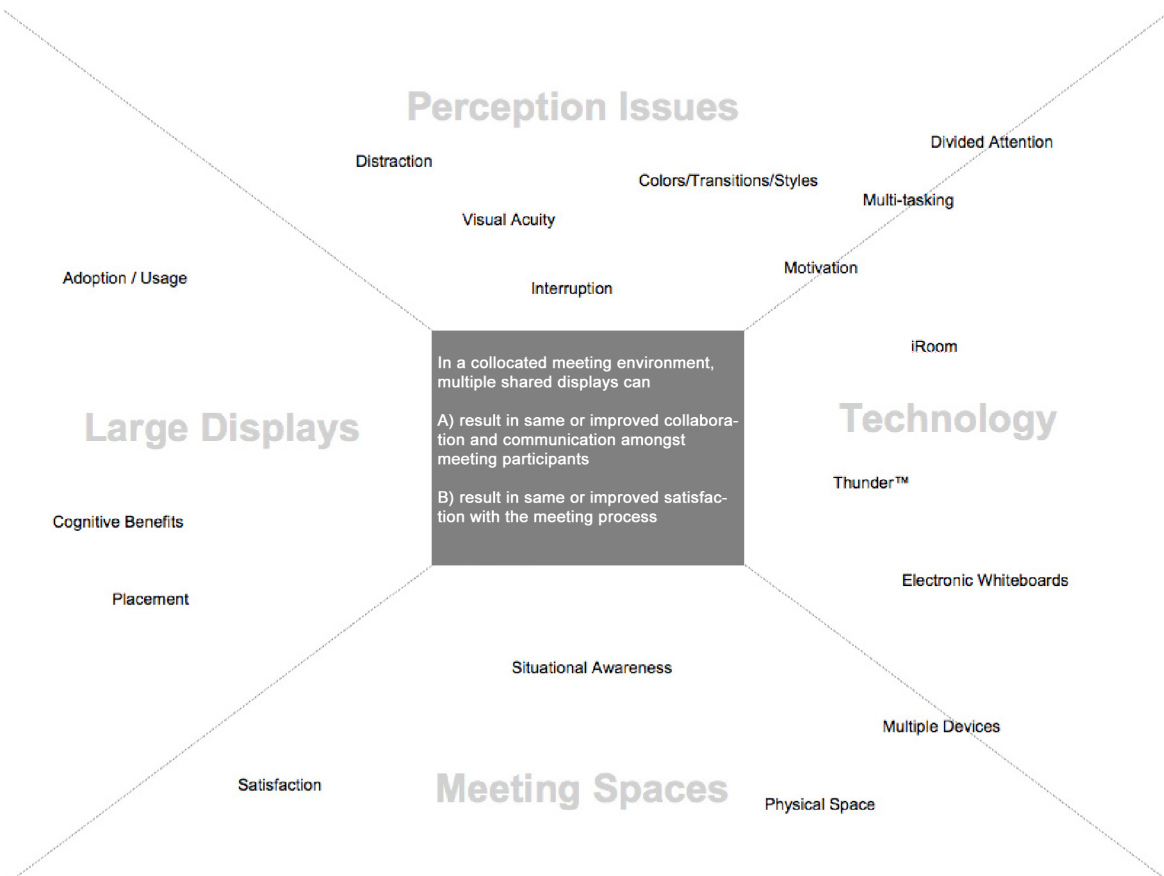


Figure 3: Related research disciplines leading to research questions.

created to support collaboration (e.g. software infrastructure, display placement), and several cognitive models. First, we begin with an overview of existing research investigating the types of tasks individuals perform while meeting.

2.1 Group Tasks

Miles identified several of the factors that contribute to the complexity of a group problem, including the amount of data, time pressures, the clarity of the goals, and ability to share data (Miles 1980). Bui and Sivasankaran created a comparison of high and low task-complexity problems, according to Miles' factors (Figure 4). Researchers also studied task complexity, notably in (DeSanctis and Gallupe 1987; Bui and Sivasankaran 1990). General findings show that as group task complexity increases, individuals may benefit from using assistive technologies (Bui and Sivasankaran 1990).

	Problem Complexity	
	High ⟷	Low
Amount of data	Large	Small
Clarity of goals	Vague	Clear
Clarity in the process of evaluating impacts of solutions	Vague	Clear
Level of responsibility in making decisions	High	Low
Perceived confidence in consequences of actions	Low	High
Perceived risks	High	Low
Time pressure	High	Low
Analyzability/structure	Low	High
Data sharing	High	Low
Conflicting value judgements of group members	High	Low

Figure 4: Miles' factors influencing complexity of a group task, contrasting low and high-task complexity problems (Bui and Sivasankaran 1990).

McGrath created a classification scheme for the types of tasks groups typically perform, as illustrated in Figure 5. McGrath established eight types of task classification including:

- **Planning** tasks, involving the generation of plans.
- **Creativity** tasks, involving the generation of ideas.
- **Intellective** tasks, involving problem-solving with a correct solution.
- **Decision-making** tasks, involving problem-solving with no definitive answer.
- **Cognitive conflict tasks**, involving resolving conflicts of viewpoint.
- **Mixed-motive** tasks, involving resolving conflicts of interest.
- **Contests/battles/competitive** tasks, involving resolving conflicts of power.

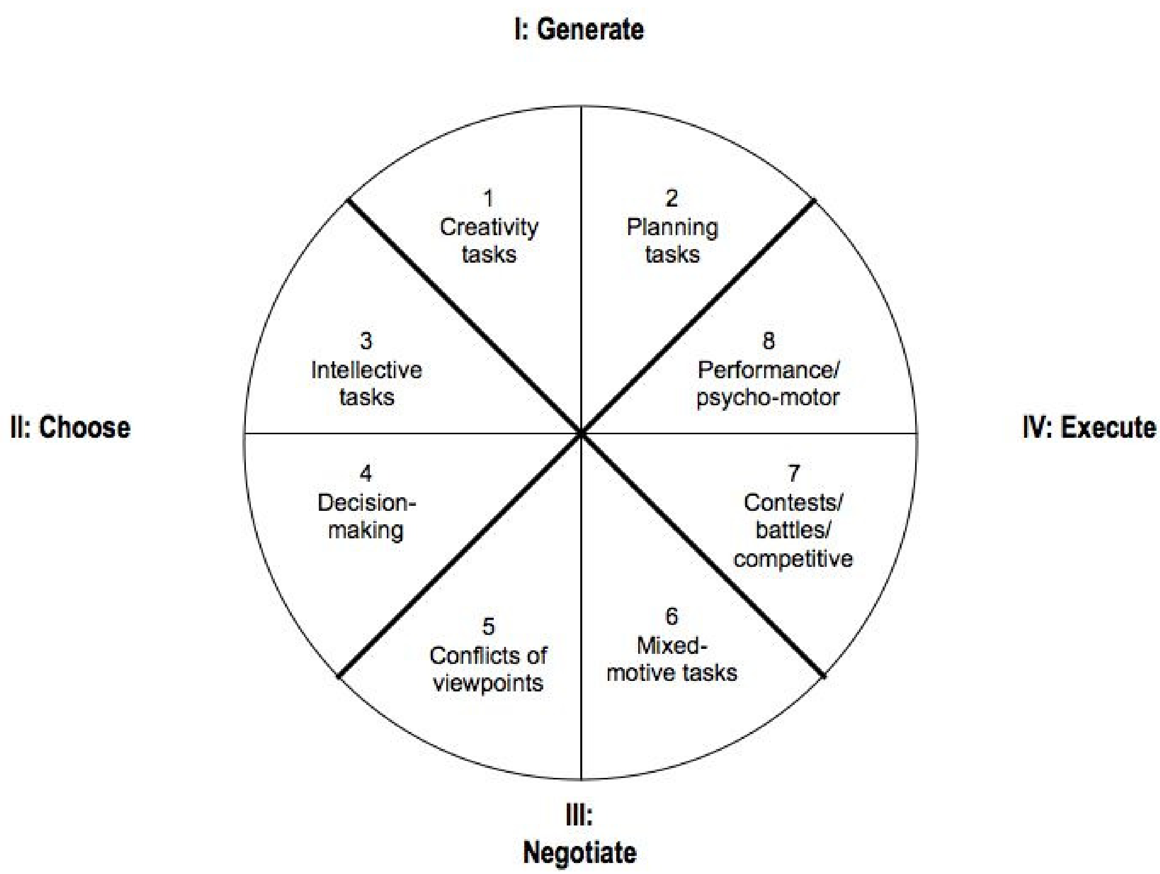


Figure 5: McGrath Group Task Circumspect (McGrath 1984).

- **Performance/psycho-motor** tasks, involving performance tasks.

McGrath further classified each task within one of four quadrants: generate, choose, negotiate, and execute, also illustrated in Figure 5. Research indicates group task evaluation studies heavily use creativity and decision-making tasks, where 41% of studies surveyed used decision making tasks (i.e. preference listing) and 21% used creativity tasks (i.e. brainstorming) (Fjermestad and Hiltz 1997). Many of the more complex types of tasks, such as intellective or planning tasks, that would likely benefit from assisted technology are not frequently used in GDSS evaluation.

2.1.1 Gesturing During Group Activities

Individuals use gestures during collaboration as a way to ground conversation, especially while performing physical tasks. Studies indicate physical gesturing can facilitate performance when individuals perform collaborative tasks (Cassell 1998; Fussell, Setlock et al. 2004). In fact, individuals are typically unaware of the amount of physical gesturing he or she engages in while performing collaborative activities (Cassell 1998). Gesturing typically occurs in one of four patterns (McNeill 1992):

- **Deictic**: pointing gestures to refer to objects or locations. This is typically performed by an index finger or entire hand.
- **Iconic**: representational hand movements to demonstrate some action or an aspect of an event, such as twisting one's hand to show how to turn a door knob.
- **Metaphoric**: representational hand movements to an event that does not have a physical form, such as using one's hands to perform a rolling motion to indicate, "wrap it up."
- **Beat**: small movements of hands that do not change with the accompany speech

Research within the HCI community often focuses on using gestures as an input language class. For example, multi-touch interfaces use swiping or pinching gestures as input mechanisms to replace commands performed via keyboards or mice, e.g. (Tse, Shen et al. 2006). Rather, in this dissertation, we are concerned with the unplanned gestures that people make during their everyday communications, specifically in reference to shared displays in meeting environments. Since gesturing is linked to task performance, it provides a metric to evaluate collaborative aspects of meetings. Furthermore, Cassell showed gesturing is important for interpreting the communication intent of an individual speaking (Cassell 1998).

2.2 Multiple Display Usage: Individual Work

Extensive research on multi-display environments (MDEs) focused on individual environments. Grudin's initial research into this area discussed that multiple display workstations offer subjective benefits to knowledge workers and provided several notable observations (Grudin 2001). Specifically, users typically distribute tasks across dual displays in several manners, including using one display for primary tasks and using the secondary to provide support for the primary task. Others use both displays equally, such as copying material from one display to a second one, while others use a second display to keep personal resources visible. Hutchings *et al* designed and deployed a software tool amongst single- and multiple-monitor users to capture window management activity, finding that window visibility can be a "useful measure of user display space management activity" (Hutchings, Smith et al. 2004). It is important to note that content that may not have active focus (using the traditional desktop user interface metaphor) is often still relevant to a user. That is, peripheral information awareness is important to multiple-monitor users.

Later work focused on capturing quantitative evidence showing performance benefits of large pixel spaces, including multiple monitor configurations. Czerwinski *et al* showed task performance benefits of using larger displays for individual users (Czerwinski, Smith et al. 2003). More recent research by Kang and Stasko compared how users completed a trip planning exercise, simulating the multiple software applications and Web pages one would typically use to plan such a trip. Kang and Stasko found that having multiple displays resulted in users completing the task in a shorter amount of time with less of a subjective workload (Kang and Stasko 2008). Thus, research shows subjective and measurable performance benefits of multiple displays for individual users, but it is unclear whether these advantages extend to groupwork.

2.3 Technology in Meetings

Recent research explored personal technology usage in meetings, such as enhancing a mundane and routine activity or investigating the disruption of technology on the meeting process. In the latter case, research indicates that interaction with computers results in individuals disengaging from conversations. Any disengagement from conversations lasting longer than 10 seconds is deemed socially unacceptable. (Newman and Smith 2006).

Newman *et al* studied technology usage in a conference room, specifically focusing on developing technologies to better support “unremarkable” activities that occur in people’s everyday lives (Newman, Ducheneaut et al. 2006). One such example is the ubiquitous action of connecting a VGA cable to a laptop computer in order to use a shared display, such as a projector or large flat panel display. While constructing their software infrastructure to better support this routine activity, these researchers counted room and personal device usage. Newman *et al* reported a generally low percentage (26-29%) of meeting room attendees bringing in personal technology to meetings, noting that the decision to bring in a personal device, such as a laptop or tablet PC, was a personal preference. We further note that corporate or institutional policies, social norms, and target audience all are other factors that may contribute to the presence and usage of personal technology within meeting spaces. Newman *et al* also did not explicitly describe the situations in which their enhanced display capabilities were used, and also did not report on the situations in which displays, laptops, and other devices were used during initial observations.

It is clear, however, that meeting rooms are a complex ecology of people, devices, and information. We believe understanding *how* and *why* devices are used, in particular with shared displays, is important for technology designers to understand challenges for real world adoption. We examine these relationships within this dissertation.

2.3.1 Group Decision Support Systems (GDSS)

A group decision support system (GDSS) supports the exchange of ideas, opinions, and preferences within a group (DeSanctis and Gallupe 1987; Gallupe, DeSanctis et al. 1988). Such a system may be categorized by one of three levels:

Level 1: a system that supports communication amongst the group to facilitate interpersonal sharing of ideas, opinions, and preferences.

Level 2: a system that provides modeling and mathematical techniques

Level 3*:* a system using machine-induced group communication patterns and can include expert advice in the selecting and arranging of rules to be applied to a meeting

The notion of a Level 1 GDSS is directly related to multiple-shared displays within a meeting space. A Level 1 GDSS supports group needs of sending and receiving information efficiently among all individuals in the group, typically via electronic-messaging, and also affords each attendee access to personal data files. Another key feature of a Level 1 GDSS is the ability to display ideas, concepts, and charts to individuals, requiring a large common viewing screen, or the ability to share one's individual computer display. DeSanctis and Gallupe also argue that a Level 1 GDSS needs anonymous messaging or voting features as a way to alleviate the reluctance of some group members to speak.

While lacking some of the features of a full-fledged Level 1 GDSS, a shared multiple display configuration offers many of the same advantages, such as displaying information to all members of the group simultaneously. Having multiple, shared displays theoretically increases the amount of information that can be displayed, allowing individuals the opportunity to augment, compare, and contrast material. Furthermore, as noted earlier, laptop computers are frequently assigned to knowledge workers. Combined with increasing wireless networking, workers with laptops have access to personal data files within meeting rooms as well as access to email communication, fulfilling another dimension of a Level 1 GDSS.

Several researchers classified GDSS evaluation research (Fjermestad and Hiltz 1998; Benbasat and Lim 2000). The most frequently supported tasks used by GDSS evaluations include brainstorming/idea generation, followed by ranking tasks. Researchers found that as task complexity increases, the decision quality and depth of analysis improve within groups using a GDSS (Bui and Sivansankaran 1987; Bui and Sivasankaran 1990). This is logical—individuals navigating through a highly complex problem space can benefit from tools serving as memory aids, or managing information. Therefore, it is interesting to note that the majority of experiments studying GDSS's used relatively short and simple tasks that are least likely to need nor benefit from the additional support (Fjermestad and Hiltz 1997).

There is, however, conflicting evidence of whether the presence of a GDSS impacts the amount of time a group takes to reach a decision. Gallupe et al found GDSS usage did not affect the decision time for complex tasks, but Bui and Sivasankaran found that groups performing low complexity tasks using a GDSS actually required more time than individuals not using the system, however this was not the case for groups performing highly complex tasks. Therefore, it is not clear if multiple shared displays will impact performance, as measured by completion times.

Miner offers several implications for GDSS design (Miner 1979). First, GDSS's need to accommodate a wide-range of decision processes in groups. Meeting styles and formats are not consistent between meetings. Second, a large number of groups can benefit from tools that allow them to plan a meeting strategy. Lastly, Miner argues that GDSS's should also aim to support both the social needs as well as their task-related activities.

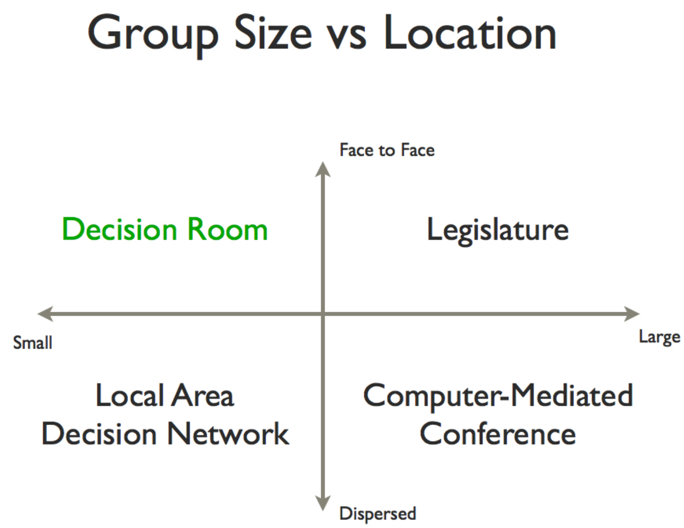


Figure 6: Group size taxonomy (DeSanctis and Gallupe 1987).

In this dissertation, we focus on the presence of multiple shared displays within meeting environments. Such a configuration meets Miner's criteria. For example, an individual can use the many *familiar* features available on his or her laptop to support a wide variety of decision processes, such as using the text editor feature of their laptop computer with a shared display to keep track of brainstormed ideas, or share a document with team members, or use commercial collaboration software such as Microsoft SharePoint. Likewise, individuals can use other built-in features of their laptops to plan a meeting strategy, such as creating an agenda together and using a clock/timer application to facilitate time management. Also, because individuals have their personal devices with them during meetings, they can use the shared displays to show information that may not be relevant to the task at hand, but is personally-relevant. For example, one attendee might ask a coworker about his or her recent vacation, and the coworker then shares several photos taken, supporting the social aspects of the meeting process.

Figure 6 shows DeSanctis and Gallupe's taxonomy of group size and co-location status of group members. We note that the settings depicted in Figure 6 are not mutually exclusive. Our research focuses on the *decision room* quadrant, where meeting attendees are primarily within the same physical location.

2.3.2 Futuristic Prototypes

Meeting spaces vary tremendously in the amount of technology provided as well as what devices are brought into the space by participants. At one extreme of the spectrum, the Stanford iRoom project (Johanson, Fox et al. 2002; Johanson, Fox et al. 2002) represents a computationally-rich physical environment. The iRoom project investigates technology interaction models for physical spaces, with specific emphasis on the use of large walk-up displays, most of which are interactive. The iRoom contains a wide-variety of displays including three interactive SmartBOARDs, one non-interactive tabletop display, and a graphical mural. The overarching research questions for iRoom concern developing a mechanism for interaction with large displays, such as the LumiPoint system, where computer vision is used to process laser pointer gestures on a large tiled display (Davis and Chen 2002). The level of integration of devices and displays makes the iRoom perhaps best suited for highly collaborative sessions, and provides an abundance of technology for meetings that revolve primarily around one or two speakers.

Other prototype research investigated interactive large displays supporting collaboration. The physical size of large displays easily allows several individuals to manipulate and share content. Many different form factors of large displays exist, some include tiled displays with bezels removed, other tiled displays use back-projection to create a large seamless surface (Raskar, Welch et al. 1998). Little work has been done, however, to understand what content should be on the displays and how effective they were.

Recently, researchers developed the IMPROMPTU framework to assist users in sharing information across displays using off-the-shelf products, thus supporting opportunistic and short-lived collaborative moments (Biehl, Baker et al. 2008). Field studies showed that users found advantages in using the framework, however, we note that the observed populations were two software engineering teams, representing a possible bias towards using and appropriating digital technology

Other display technologies found in meeting spaces include interactive whiteboards, becoming popular in the early 1990s (Pederson, McCall et al. 1993) and now

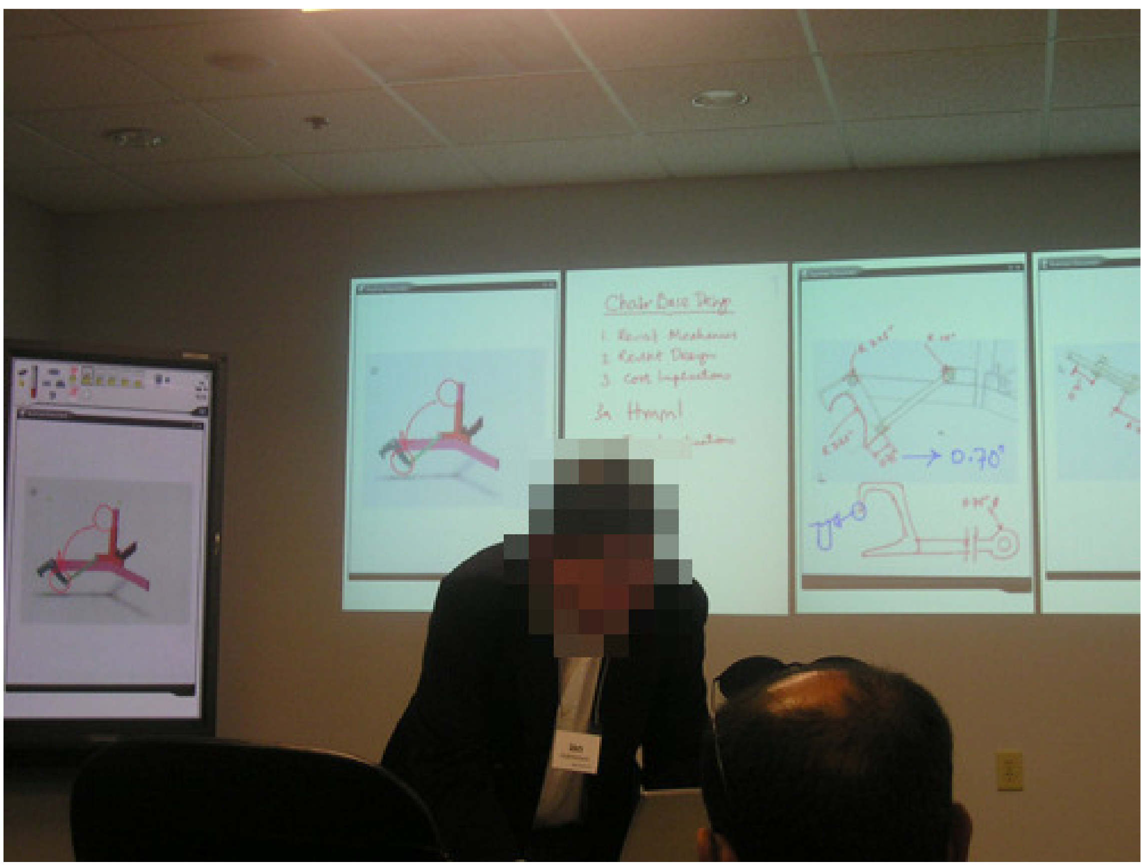


Figure 7: PolyVision Thunder virtual flip chart system, consisting of a large electronic whiteboard and multiple secondary displays.

commercially available by several vendors. Typical large displays include projectors or large flat panel monitors that enable a user to share content from a room-based computer or an individual's laptop. Several commercial products attempted to incorporate multiple display devices for meeting environments, like Polyvision's Thunder system, shown in Figure 7 (2007). Thunder used an electronic touch-screen display and multiple projectors to create a virtual flip-chart system to support in-room or distant collaboration. PolyVision researchers conducted observational studies in a variety of environments, learning the ability to persistently display information is often important for users. Therefore, Thunder users were quickly able to archive a page of the virtual flipbook and display it in the environment. However, as of January 2009, this product is no longer be sold by PolyVision.

Figure 8: Steelcase Leadership Collaborative featuring eight secondary displays (photo courtesy of Steelcase Inc.)

Currently, large meeting spaces sometimes mirror content on multiple displays to ensure visibility for all positions in the audience. While iRoom represented a research endeavor into technology in collaborative spaces, Steelcase's Leadership Collaborative (Figure 8) illustrates an industry approach to a high-technology meeting space that is used on a daily basis (Kirkbride 2006). The Leadership collaborative contains ten large LCD displays, where eight are configured to display a variety of peripheral information (i.e. stock performance, news headlines, meeting participants' content.) In this design, information has "a seat at the table" amongst participants, achieved by placing the primary displays at table-height at both ends of the table. Also, the Thunder virtual flip-chart system is installed within the space. Perhaps most innovative in this installation is the ability for each meeting participant to connect a notebook computer to any of the ten LCD screens.

The designers of the Leadership Collaborative view the ability to share and keep information persistent very important, as evident by the large number of displays included in the space. The research questions posed in this dissertation also explore the impact of multiple shared displays on the types of collaboration activities in meeting rooms. We are exploring the benefits and disadvantages of placing this information on secondary displays.

While Steelcase's Leadership Collaborative and the Stanford iRoom represent the extreme of technologically rich environments, it is unreasonable to assume that the majority of corporations and academic environments are outfitted in this manner or will be in the near term. As noted, several corporations already attempted to market technology systems for meetings (i.e Polyvision's Thunder system). These systems are not widely deployed due to high costs and a general lack of knowledge of benefits gained—and again, the PolyVision Thunder system is no longer listed for sale. However, we note that workers actually do use the information-rich environment of the Leadership Collaborative at Steelcase and remark that the access to information and displays is a highly-powerful tool for collaboration sessions (Kirkbride 2006). Any individual with a computing device and an Internet connection has the ability to research and retrieve information on the fly and share it with other individuals, thereby transforming this combination of individuals, laptops, Internet access, and displays into a group decision support system.

2.3.3 Large Displays & Placement

Large displays support collaboration by allowing meeting participants to easily view information from each seat location. The CSCW community has researched the role of large public displays within collaboration, with special emphasis on usage and adoption factors.

Czerwinski *et al* showed cognitive and performance benefits of using large displays for single users (Czerwinski, Smith et al. 2003). At this point, however, it is not clear whether multiple displays offer an advantage over a single large high-resolution display. Baudisch, on one hand, showed that there are performance benefits due to the increased field of view with larger displays, even if the periphery of a large display is not kept in high resolution (Baudisch, Good et al. 2002). However, a single large, high-resolution display costs more than multiple smaller displays. When designing meeting spaces, the additional costs of a single high-resolution display or multiple displays may be difficult to justify to facility managers if performance benefits are unknown.

Huang explored the challenges associated with the adoption of large public displays, acquired through a survey of large-display groupware systems (Huang, Mynatt et al. 2006). She identified four factors influencing adoption of these systems:

- **Form factor**: larger displays are viewed from further distances
- **Public audience and location**: shared/public spaces influence how much attention is paid to these displays
- **Outside personal workspace**: users interact differently with displays outside of their workspace
- **Group-owned**: users feel less of a sense of personal ownership over the displays

Although Huang focused on interactive groupware displays, her criteria are relevant towards this research. Secondary displays placed within a meeting environment are shared, public resources outside of one's traditional personal workspace. Therefore, traditional interaction techniques do not necessarily apply in this domain. A challenge for meeting display designers is creating a sense of ownership for users and increasing the desire to use the technology. Allowing a display to be temporarily annexed by an individual can create a sense of quasi-personal ownership.

Huang also presented a case study of a large interactive display system, examining this system in relationship to other technologies in the environment (Huang, Mynatt et al. 2006). Key findings included discovering that as assignments progressed, individuals' needs and requirements of the large display changed substantially. For example, a display might transition from interactive usage towards becoming an ambient display—that is, a display that resides in the periphery of attention communicating information that is non-critical in nature (Plaue, Miller et al. 2004). This key finding is often overlooked by display designers—individuals' perceptions and usage of a system do not remain constant over time. Therefore, multiple shared displays within meeting environments must be robust and flexible, supporting more than one task, or risk not being adopted by users. Furthermore, interaction with these displays needs to support existing work habits.

Su and Bailey investigated the placement of large displays in interactive environments (Su and Bailey 2005), more specifically on how physical separation and angle between displays impacted user performance and subjective workload. Su and Bailey had participants work at a meeting table with two 61" plasma displays present in a variety of configurations. Participants moved windows from one display to a target area on another display, mimicking the need for individuals to manage screen real-estate. They produced three design recommendations:

- Displays can be separated on a horizontal plane up to a subtended visual angle of 45˚.
- Displays should not be placed behind a user.
- Displays should be positioned at a 45˚ angle relative to each other rather than being orthogonal.

Su and Bailey's work is directly relevant to this dissertation research in that they examined one important design attribute, where large displays are placed. However, the tasks users performed in the study were direct-manipulation in nature, requiring hand-eye coordination, while my work focuses on displays that are typically used to mirror content from a laptop computer, a common activity occurring in meeting rooms. Furthermore,

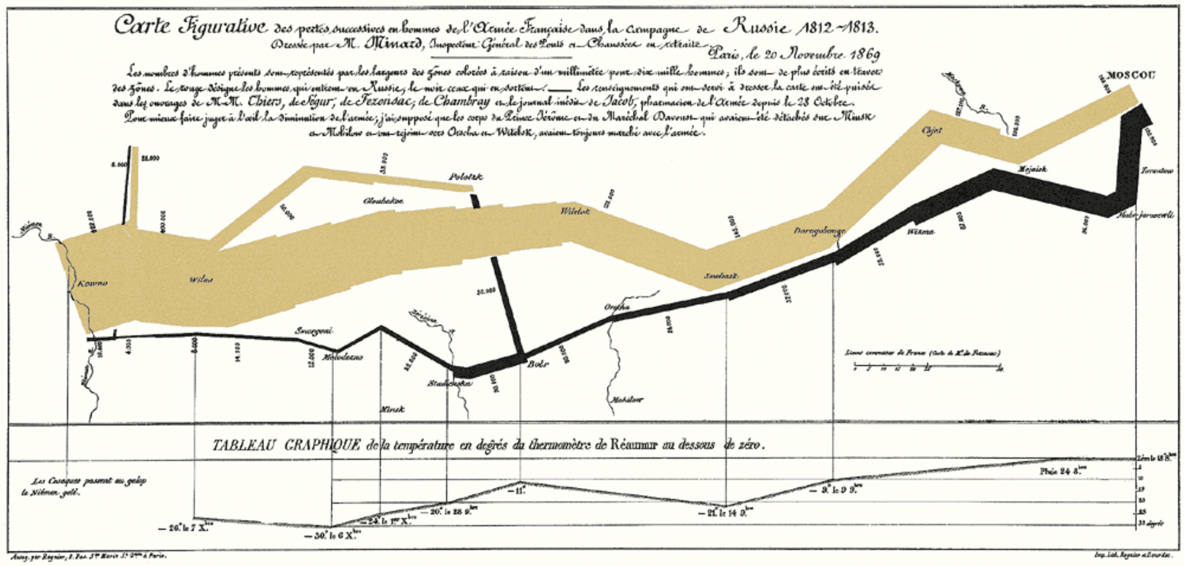


Figure 9: Napoleon's March to Moscow by Charles Minard, from (Tufte 2001).

meeting attendees might use multiple shared displays within meeting rooms for peripheral information monitoring. Their design recommendations refer to the viewing angle of displays and thus are relevant towards secondary display placement.

2.4 Visualizations

An inherent challenge in collaboration technology research is data analysis—how can a researcher understand the multiple activities that may be occurring in parallel. In this dissertation, we seek to use techniques from information visualization research to create effective ways to explore low-level collaborative activities and events, supplementing traditional qualitative and statistical analysis techniques.

2.4.1 Time-Series Data visualizations

A significant amount of research within the information visualization community focuses on data that has some temporal component to it (Shneiderman 1996). Time series data can be defined as a sequence of N pairs (a_i, t_i) where $i = 1, 2, \ldots, N$ and a_i is a measured value of some event or action at time t_i (van Wijk and van Selow 1999). As defined, most collaboration in meeting spaces are complex versions of time series data, where at any particular instant in time, an individual may be speaking, gesturing, using technology, or performing some other activity.

Aigner *et al* note that temporal visualizations, such as visualization meeting processes, offer challenges to researchers (Aigner, Miksch et al. 2008). These challenges include visualization scalability issues when there are large amounts of temporal data. Another challenge for researchers is maintaining a user- and task-centric design methodology, such as affording easy user-manipulation of visualization parameters.

One example of effective time-series visualization is Charles Minard's graphic illustrating Napoleon's March during the War of 1812, shown in Figure 9. This visualization uses spatial dimensions to illustrate linear time and applies visual encodings to illustrate the direction of the war campaign, size of the army, and ambient temperature. We note the Minard visualization for its excellence in allowing the viewer to facilitate the spotting of trends and anomalies within the data, which are our main objectives in visualizing the types of time-series data that occur during meetings.

2.4.2 Time-Series Tasks

Effective time-series visualization systems support typical tasks for exploring data, including (Müller and Schumann 2003):

- Does a data element exist at a specific time?
- When does a data element exist on time? Is there any cycling behavior?
- How long is the time span from beginning to end of the data element
- How often does a data element occur?

- Do data elements exist together?

Considering the types of activities that are likely to occur within a single meeting or collaborative session, a meeting visualization will focus on linear time (versus cyclic time) and needs to consider the potential for branching time. For example, a group may subdivide into smaller groups while engaging in collaborative activities. Figure 10 illustrates a taxonomy of various time-series visualization parameters. Activities occurring in meeting rooms typically will use interval points, linear time, and include aspects of both ordinal and continuous time.

Shneiderman also listed tasks that visualization systems should offer (Shneiderman 1996):

- overview of the data such that the user can see the entire collection
- zooming abilities (to focus on items of interest)
- filtering (to remove uninteresting items)

Discrete Points Time is abstracted	←→	**Interval Points** Uses scaled time axis
Linear Time Starting point outlying data elements from past to future.	←→	**Cyclic Time** Cyclic time axis used to show natural cyclic processes
Ordinal Time Elements are classified occurring “before” or “after” each other.	←→	**Continuous Time** Able to quantify time differences between elements
Ordered Time Events happen consecutively	**Branching Time** Sequences of actions can occur (i.e. multiple alternatives)	**Time with Multiple Perspectives**

Figure 10: Taxonomy of time-series visualization parameters. (Frank 1998; Müller and Schumann 2003)

- details-on-demand (to gain more information when needed)

2.4.3 Time-Series Visualization Systems

Researchers created several time-series visualizations of interest. LifeLines consolidated personal history data (i.e. medical histories) via interactive software that visualized quantitative data values as they relate to points of time (Plaisant, Milash et al. 1996). Attributes of this system include an overview view to show multiple concurrent aspects of an individual's life, using icons to illustrate events, and varying color and line thickness to illustrate relationships.

Several researchers explored visualizing other aspects of office life. Notably, Mackinlay *et al* created Spiral Calendar and Time Lattice to improve access to large masses of time-based information (MacKinlay, Robertson et al. 1994). Spiral Calendar showed individuals' daily schedules and uses a spiral metaphor to represent the cyclic nature of the workday. Time Lattice showed a series of individual's 2D calendars to compare schedules amongst a group of people. Furthermore, van Wijk and van Semok visualized electrical power demand at a research facility by using clustering techniques (van Wijk and van Selow 1999), illustrating variations in consumption over cyclic time periods and the corresponding implication on worker attendance.

2.5 Organizational Behavior and Trends

Current trends within organizations' employee structures indicate a shift away from traditional hierarchies to flat, low-hierarchies utilizing self-managing teams (Owens 2000; Peeters, van Tuijil et al. 2006). Such a shift impacts meetings, where team members must make decisions together rather than having one made for them. These trends are echoed in data indicating that individuals, especially managers, are spending an ever-increasing amount of their workday in meetings (DeSanctis and Gallupe 1987; Nunamaker, Applegate et al. 1987; Rogelberg, Leach et al. 2006).

As a result of this increased amount of time spent in meetings, researchers found a significant relationship between the number of meetings attended and daily fatigue as well as subjective workload (Luong and Rogelberg 2005). Furthermore, perceived meeting effectiveness is correlated to job attitudes and well-being (Rogelberg, Leach et al. 2006). Therefore, it is not surprising that a significant amount of research over the past few decades has investigated the meeting process to understand the social and informational dynamics that occur in order to better facilitate meetings, as well as understanding the role technology plays in collaboration.

The onset of a meeting is "characterized by uncertainty cautious interaction, and concern for integration" (O'Connor 1980). After this initial uncertainty, activities differ radically from meeting to meeting, group to group. Furthermore, the pattern of interaction between a team is observed to change as a meeting progresses. For example, at different points during the meeting process, team members may interpret comments differently or apply different decision making rules (Poole, Seibold et al. 1985). The only consistent pattern of behavior noted by Poole, Seibold et al are two major interaction patterns: task-oriented or social-needs interaction. Task-oriented patterns of behavior involve

Table 1: Behaviors and activities correlated to social status in meetings (Owens 2000).

Status Stratum	**Relevant Behavior**	**Primary Domains of Activity**
High Status	Dominating: interruption, participant control, threats	- perform high-level task guidance - control status interactions - define, reinforce status currency. - stabilize group status order
Medium Status	Contesting: Framing social capital, expertise framing, jargon, challenge others	- perform primary task activities - contest task approaches - offer competing problem definitions - =move higher in the status order - contest status quo
Low Status	Integrating: ingratiation, Supplication, volunteering	- perform peripheral support tasks - enhances socio-emotional climate - become integrated in group - reinforce group status order

completing the issue at hand, while social-needs patterns involve releasing tension and addressing solidarity (Bales and Strodtbeck 1951; Poole, Seibold et al. 1985).

Social status also plays a large role in meeting dynamics. Owens proposed a three-tiered status model that considers how individuals' behaviors act to reinforce the social status of the group member (Table 1). For example, individuals with lower status in the stratum will be more passive, relegating themselves to the background, and generally only voice input when directly asked. Individuals with higher social status will generally dominate the dialog within the meeting and often make decisions for the group. Social status is influenced by personality traits and dispositions as well as job experience and age.

Personality traits and dispositions are inherently difficult to influence within an organization. However, research does suggest that a more logical approach to improving team meeting experiences is to focus on members' knowledge, skills, and abilities (KSAs), and to develop technologies that support individual items (Stevens and Campion 1994) In additional to developing technology to support these attributes, training programs provided by management can also be used to influence individuals' KSAs. Stevens and Campion identified 14 team member KSAs occurring in research literature, summarized in Table 2.

Generally speaking, meetings occur in one of two major styles: *leader-led* or *collaboration-style,* or a mix of both. A collaboration-style meeting is democratic in nature where participants actively work together. The decision to work in either style depends on the tasks, situation, and technology available (Mark, Haake et al. 1996). For example, Posner and Baecker interviewed writers and found that time pressures, project phase, management styles, relationships, and personal preference will influence what style of meeting is used (Posner and Baecker 1992).

Table 2: Fourteen team member knowledge, skills, & abilities (Stevens and Campion 1994).

INTERPERSONAL KSAs

A. Conflict Resolution KSAs

1. The KSA to recognize and encourage desirable, but discourage undesirable, team conflict.
2. The KSA to recognize the type and source of conflict confronting the team and to implement an appropriate conflict resolution strategy.
3. The KSA to employ an integrative (win-win) negotiation strategy rather than the traditional distributive (win-lose) strategy.

B. Collaborative Problem Solving KSAs

4. The KSA to identify situations requiring participative group problem solving and to utilize the proper degree and type of participation.
5. The KSA to recognize the obstacles to collaborative group problem solving and implement appropriate corrective actions.

C. Communication KSAs

6. The KSA to understand communication networks, and to utilize decentralized networks to enhance communication where possible.
7. The KSA to communicate openly and supportively, that is, to send messages which are: (1) behavior- or event-oriented; (2) congruent; (3) validating; (4) conjunctive; and (5) owned.
8. The KSA to listen nonevaluatively and to appropriately use active listening techniques.
9. The KSA to maximize consonance between nonverbal and verbal messages, and to recognize and interpret the nonverbal messages of others.
10. The KSA to engage in ritual greetings and small talk, and a recognition of their importance.

II. SELF-MANAGEMENT KSAs

D. Goal Setting and Performance Management KSAs

11. The KSA to help establish specific, challenging, and accepted team goals.
12. The KSA to monitor, evaluate, and provide feedback on both overall team performance and individual team member performance.

E. Planning and Task Coordination KSAs

13. The KSA to coordinate and synchronize activities, information, and task interdependencies between team members.
14. The KSA to help establish task and role expectations of individual team members and to ensure proper balancing of workload in the team.

2.6 Cognitive Frameworks

Finally, to investigate the impact of multiple shared displays on collaboration, we need an understanding of the cognitive abilities and limitations of individuals. Collaborative environments involve large amounts of information, multiple trains of thought, and individuals who may be multitasking. Thus, research within collaborative environments requires an understanding of how the mental capabilities of individuals can adapt to or be limited by the demanding environment.

2.6.1 Attention

Attention is generally understood as a concentration of mental activity and can occur in both divided and selective forms. Classical cognitive psychology laboratory testing indicated that the human perceptual system can handle some divided-attention tasks, but fails when the tasks become too demanding (Matlin 1998). Furthermore, when attention is divided, humans often fail to perceive stimuli correctly. This is a concern for shared display designers in meeting spaces, due to the inherent multi-tasking that frequently occurs.

However, classical psychology research indicates that tasks associated with divided attention are performed better over time, after a user performs additional practice (Hirst, Spelke et al. 1980). Hirst further argued that practice can alter the limits of attention capacity. Furthermore, Allport showed that humans do not appear to have a fixed limit to the number of tasks that can be performed simultaneously (Allport 1989).

Recent research on divided attention indicates that it is very difficult, or impossible, to fully automate performing two tasks at the same time, since many real-world tasks contain many different subtasks and much of the mental processing is nonrecurring (Strayer and Johnston 2001; Lien, Ruthruff et al. 2006). Lien et al note that it is possible, with good device design and training, to improve the reliability of multi-tasking performance.

When presented with multiple tasks, humans are able to focus their attention on one task while disregarding the others through the use of selective attention. Laboratory studies have shown that participants tend to notice little about the tasks that are not being focused on. Evidence of this phenomena occurred in the evaluation of BlueGoo, a peripheral display that visualizes news feeds in the form of animated collages (Plaue and Stasko 2007). Participants performed a primary Web browsing task while BlueGoo collages were active in the periphery. Most participants who were not informed of the presence of the BlueGoo system did not report noticing the display nor could recall any information that was presented.

Similar findings have been discovered in previous studies. Individuals exhibit the ability to focus intently on one task—a form of tunnel vision—when under stress, such as a deadline (Williams 1985). However, stressful conditions can also cause one's attention to widen. Wickens found that the cognitive load and stress level of an individual impacts attention towards items in one's periphery (Wickens 1992). Individuals exposed to a higher stress level often experience psychological arousal and are much more alert and aware of surroundings.

In addition, four cognitive resource models view humans as having limited cognitive resources, thus assuming that these resources can be allocated as necessary (Fitts and Posner 1967; Norman and Bobrow 1975). These models include:

- **Resource-limited** model: tasks require the full amount of resources available to maximize performance
- **Data-limited** model: tasks require only a partial amount of resources available to get maximum performance
- **Automated** model: tasks that demand no resources

- **Divided-attention model**: Cognitive resources are shared between primary and secondary tasks, and primary task performance can be both resource and data-limited

These cognitive resource models are useful for technology researchers in modeling how meeting attendees divide their attention between group and individual tasks, as well as how attention is divided between technology and information.

2.6.2 Multiple Resource Theory

Multiple resource theory (Wickens 1980; Wickens 2002) claims that the amount of cognitive resources is limited by each individual; when the demand for these resources becomes too high, performance degrades. Wickens distinguishes multiple resource theory as not being exclusively a theory of attention or workload. Specifically, Wickens argues that the concept of attention is important in dual-task studies, but attention also involves a sense of awareness. Multiple task performance studies often do not assess awareness since these studies are strictly controlled, dual-task situations. Likewise, Wickens claimed that although workload theories have much to do with cognitive resources, they are insufficient for describing multitasking situations since these theories often do not address multiple simultaneous sources, such as those commonly occurring within a collaborative environment

Wickens presented the multiple resource theory (MRT) model via four dimensions (Wickens 2002):

1) **Cognitive vs response *stages***
2) **Auditory vs visual *sensory modalities***
3) **Visual vs. spatial *codes***

4) Focal vs. ambient *channels*

The four-dimensional multiple resource theory is applied to predict human performance in multi-tasking situations. For example, there will be greater interference between two tasks if they share any stages, sensory modalities, codes or channels of visual information, thus decreasing performance for those tasks

Multiple resource theory provides a useful tool for analyzing meeting and collaboration performance as well as study design. If participants in a laboratory study are motivated by financial reward to complete some primary task, this induces a stress-like condition that causes individuals to disregard information presented in the periphery. Furthermore, if meeting participants are multi-tasking, how much "damage" is being done to the information conveyed by an individual communicating information? Most existing dual-task research is based upon divided attention studies where two tasks are relatively independent. However, in a collaborative meeting environment, different meeting-specific tasks may require shared displays to be used independently or dependently, and use the same modality.

2.6.3 Situational Awareness

Closely related to the notion of attention limitations, situational awareness (also commonly referred to as situation awareness in literature) is defined as "*the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*" (Endsley 1988). In more general terms, situational awareness refers to being able to maintain consciousness of one's surroundings including people, objects, technologies and any other factors that contribute towards the performance of some task. Situational awareness is generally considered individual-centric and is viewed as an individual skill or ability (Artman and Garbis 1998).

Edsley defines situational awareness in terms of three levels:

- **Perception**
- **Comprehension**
- **Projection**.

In the perception level, a user isolates elemental cues within the environment. During this process, individuals acquire information about the state of these cues, such as location, physical attributes, and proximity to other cues. The second level of situational awareness refers to the comprehension of what the elemental cues mean. This is a dynamic process that results from the mental organization of the cues toward the main task or goal at hand. Finally, the third level of situational awareness refers to the ability to project future states from past experiences. Individuals who are considered to be well experienced at a particular task, gambling or playing cards, for example, use this level of situational awareness to form a competitive advantage over others.

Selective attention is crucial to the success of accomplishing a task under situational awareness. Using past experiences, one must be able to quickly learn which cues to attend to and which to avoid. For example, in the complex task of driving a car or flying an airplane, focusing attention on just one object or person will be just as ineffective or detrimental to accomplishing the task as a whole as trying to attend to every single environmental cue encountered. However, individuals do take each new experience and add it to their knowledge base for future assistance in interpreting of new cues.

Although situational awareness is generally thought in terms of the individual, work is often performed in group or teams, so a slight modification of the definition of situational awareness is needed. Artman and Garbis define team situational awareness as “the active construction of a model of a situation partly shared and partly distributed between two or more agents from which one can anticipate important future states in the near future” (Artman and Garbis 1998).

Historically, situational awareness has been studied with respect to airplane cockpits and control room design (e.g. (Adams and Pew 1996)). Aircraft, for example, contain a variety of instrument readings, checklists, memory recall activities, and the interaction of several crewmembers. In addition, the agents involved in a cockpit typically have one goal in mind, to safely fly the airplane.

Meeting spaces represent a different domain, although with some similarities. Multiple agents are involved and a variety of different technologies are accessible. One noticeable difference lies in that meeting participants often multi-task with an activity not related to the main meeting task, but still need to maintain an awareness of the main meeting topic or presenter. Consider the following scenario:

> *Peter calls Linda and Ryan in for a presentation on stock performance at their respective company. Peter uses his laptop computer connected to a large LCD display to share PowerPoint slides. Linda and Ryan each have a laptop in front of them; Ryan is using his to take notes on the meeting and pull up supporting financial numbers while Linda is checking and responding to email.*

The overall goal within this scenario is to obtain information about stock performance; Peter is concerned about conveying information and Linda and Brian are concerned about receiving information. Linda and Ryan gain their level one situational awareness elemental cues of Peter, his verbal dialog and body language, and the supporting visuals being shown. Peter gains his level one situational awareness cues of the body language and activities of Linda and Ryan. Linda, notably, also has a secondary activity of email-checking that is not related to the meeting. She also has level one awareness cues associated with her email, such as a new mail notification and the status of her inbox.

The meeting dynamics of the scenario provide for interesting possibilities with the third level of situational analysis—the ability to project from past experiences to future situations. For example, Ryan might recall that Peter tends to clasp his hands behind his back when he is annoyed at the perceived lack of attention by meeting participants, so he uses this knowledge to modify his behavior during the meeting process. Likewise, Linda uses awareness cues of the presentation content to gauge when she should attenuate from her email tasks to pay attention to Peter’s presentation.

Overall, meeting environments are complex ecologies with multiple participants with varying goals and tasks. In addition, a variety of different technologies are available during the typical meeting. Situational awareness gives us the opportunity to explore each meeting participant’s mental model of the meeting activity and associated tasks, and helps individuals determine what course of action to take during an enfolding situation.

CHAPTER 3

FIELD STUDIES

Meeting spaces exist in a variety of sizes and configuration. Human-computer interaction investigators often focus research efforts on developing technological infrastructure or new interaction techniques for collaboration. However, as Streitz *et al* note, meeting spaces combine aspects of software, technology, and physical components (Streitz, Geissler et al. 1999). In this chapter, we describe fieldwork examining how employees of two different companies (which we refer to as Alpha and Beta Corporations) used technology in conference rooms, with specific emphasis on shared displays. We consider shared display usage from a holistic perspective, examining the social and technological routines occurring within these spaces. Furthermore, halfway through the observation process, we provided each meeting space with a second shared display and recorded how users approached and/or adopted the new technology, or modified any existing work practices. We specifically focus on product-oriented corporations, an area often not explored within the HCI community.

3.1 Research Questions and Hypotheses

We seek to understand three different aspects of routines occurring in the spaces: information sharing, analog and digital technology usage, and social protocols (standards of courteous behavior) with respect to shared display usage. Our intention is to use this knowledge for developing design implications for shared display technologies for meeting rooms. We placed specific emphasis on investigating aspects of collaboration and communication as well as satisfaction with the meeting process amongst attendees, before and after a second shared display is placed in the meeting room.

<u>Research Question 1 (RQ1)</u>

What attitudes and routines do people have regarding the usage of technology in meetings?

This research question explores the relationship between shared displays in meeting rooms and the technology that connects to them. Furthermore, this question explores the motivation for why individuals chose to use or avoid technology in meeting rooms. We hypothesize that individuals are likely to bring and use technology into meetings when they do not expect to participate much. Therefore, we believe individuals will use laptop computers and smartphones to multitask on activities other than the main meeting topic. More interestingly, we also hypothesize that adding a second shared display will result in more individuals bringing devices into the meeting space in order to make use of more available screen real estate.

<u>Research Question 2 (RQ2)</u>

Can a second shared display result in an improvement in the meeting experience, or is it a distraction?

Specific, in RQ2, we are probing how multiple shared displays impact the collaboration process. To understand changes upon collaboration and satisfaction with the meeting process, we must examine existing routines involving shared displays to establish a baseline to compare to. We hypothesize that since an additional shared display will allow two individuals to share information in parallel, and overall more information to be shared in general, individuals will feel more engaged with the meeting process.

3.2 Sample Populations

Alpha Corp. is a global company designing and selling office furniture, technologies, and services. Headquartered in the United States, Alpha Corp. has 13,000 employees worldwide and manufacturing facilities, dealers, and research centers across the globe. The corporate structure of Alpha Corp. is similar to other organizations of its size, representing a mix of white and blue-collar employees. A variety of different departments, divisions, and sub-units exist within the company, such as marketing, finance, sales, manufacturing, quality assurance, sourcing and shipping. Typically, employees report directly to a manager within their particular department

3.2.1 Project Room Population

One population observed for meeting space usage is the supply chain department of the company, a largely "mobile" group where approximately two-thirds of the 80 employees have no permanent cubicle or desk. Rather, each mobile employee is outfitted with a laptop computer, mobile phone or Blackberry wireless device, and one locking storage drawer to store personal belongings. Throughout the day, the individuals migrate throughout shared open-areas, conference rooms, enclaves (small enclosed rooms with seating for 2-4 individuals), or travel offsite to suppliers or manufacturing plants.

The supply chain group is collectively responsible for ensuring the availability of commodities for products within the company. In addition, they seek out ways to reduce costs and expenses. Managers oversee different product categories within the company. For example, one manager is responsible for all products within the seating category, making sure plants get components they require, such as plastic shells, casters, pneumatic cylinders, and fabric. Members of the supply chain routinely interact with individuals outside the immediate physical area, such as suppliers and manufacturing plants. Such interactions occur in both on-site visits and phone conferences with more remote locations, such as an Asian manufacturing plant.

The age of the population observed and interviewed ranged from 26-61 years. We observed and interviewed managers, product buyers, product suppliers, and account managers. Specifically, five individuals from the supply chain group were interviewed halfway through the study and again at the end.

3.2.2 Conference Room Population

Alpha Corp. wholly owns several smaller companies that develop and manufacture specialized products for office environments. One such company is Beta Corp., which specializes in developing and selling ergonomic tools such as VESA-mountable monitor arms, task lighting, and keyboard trays. Beta Corp. operates as an independent small company, but is able to leverage its parent organization’s global sales network and resources.

The employees of Beta Corp. range from engineers, industrial designers, marketing experts, financial analysts, to project managers. All individuals observed and interviewed during this study were issued laptop computers as their primary computing device. Each individual has a cubicle or desk; several individuals used docking stations for their laptops when at their desks. The age of this population observed and interviewed ranged from 29 to 45.

3.3 Observation Sites

Often overlooked by technology designers for meeting spaces is whether a meeting space is a *shared* or *owned* resource. Shared meeting spaces typically do not hold any

Figure 11: Layout of project room at Alpha Corp.

persistent content (i.e. pictures, poster boards, stick-it notes, or charts) after the meeting attendees leave the room and a cleaning staff comes through. Owned meeting spaces are typically dedicated to a particular subgroup of individuals who regularly use the space and may have persistent content in the room. Sometimes these types of spaces are known as "war rooms."

Two observation sites were chosen to explore ownership status: a shared conference room within Beta Corp. and an owned project room used by individuals in the supply chain division of Alpha Corp. These were two spaces used on a regular basis by respective company employees in which we received permission to conduct observations.

3.3.1 Project Room

This 20x20-foot meeting space is "owned" by the supply chain group and is designated a task room (Figure 11). This space consists of four sectional tables placed around a central power and data hub. Seating for up to eight individuals is provided. Initially, this space was not outfitted with a permanent projector; individuals wanting to share information typically retrieved a shared projector from a storage unit and placed it on top of the central hub at the table. Due to a lack of space for a projection screen, participants projected onto a portion of the whiteboard.

Attendees made use of the wall space in this room. One wall supports a large marker board surface. The other two walls host an abundance of physical and persistent displays including progress/update board (referred to as "accountability boards"), charts, Post-It notes, and various paper documents. The exterior wall consists of a semi-transparent full-height glass wall with six plastic holders containing paper documents.

3.3.2 Conference Room

This meeting space is a shared 20x40-foot space for the Beta Corp. organization (Figure 12). This room is one multiple shared spaces, including a large informal "family media room," several enclaves, and project rooms identical in size and lighting to the supply chain's project room. We note the availability of other rooms since individuals within Beta Corp. have a choice in reserving meeting spaces, a factor potentially influencing how the conference room is used.

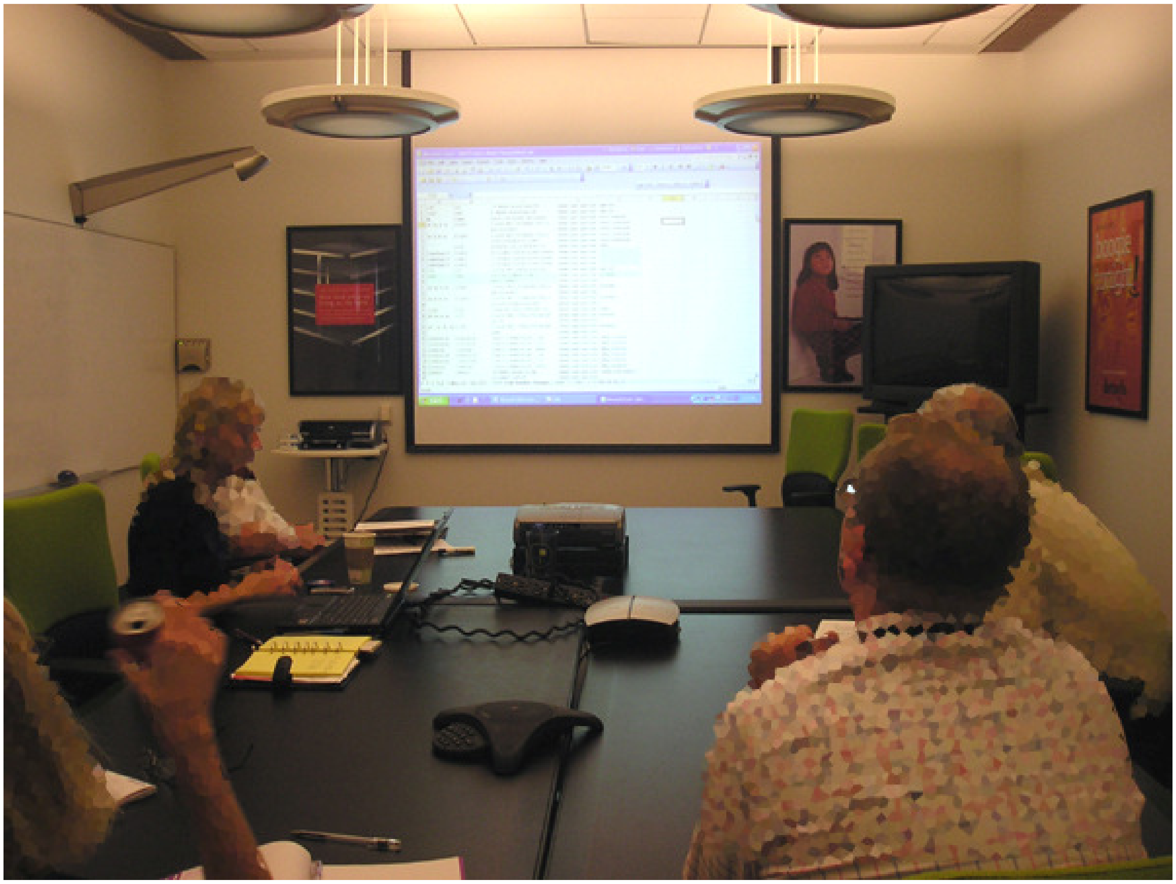


Figure 12: Layout of conference room at Beta Corp.

This meeting space has four large tables pushed together surrounded by seating for up to 12 individuals. The company equipped the conference room with a dedicated table-top XGA projector aimed at an electrically-retractable projection screen on one of the 20’ walls. One of the 40’ walls contained a large whiteboard surface, half of which can be electronically captured via a PolyVision CaptureCam (Polyvision 2007). The wall directly across from the whiteboard contained promotional images for the company.

Company employees placed a power strip on top of the tables to provide electrical power for laptop computers. Due to the unreliability of wireless Internet access within the conference room, employees purchased and installed a wired network switch with retractable cables.

3.4 Observation Method

Several previous studies of meeting spaces leveraged video capture to gain observation (Wang and Blevis 2004; Newman, Ducheneaut et al. 2006). Newman *et al.* took image snapshots at one-minute intervals from three different camera angles while Wang and Blevis used continual video observation. Both sets of researchers noted that image capture was less intrusive than direct observation and also required fewer man-hours.

However, in this study, we observed actual companies and their employees on a day-to-day basis, requiring a balancing of privacy and confidentiality. Because material discussed at meetings could contain proprietary information, several individuals expressed concern about using a continual video observation of the spaces. Furthermore, research by Hayes showed that users were reluctant to enter a space under continual surveillance, even if they had the ability to "purge" the video capture (Hayes 2007).

We also decided against using image sampling at regular intervals as our method of observation due to the fact that we could potentially miss quick interactions with technology. If, for example, a camera captures approximately a one-second snapshot every minute in time, approximately 98% of a 30-minute long meeting would not be captured. During preliminary observations, the temporal resolution of several interactions with technology occurred in about 30-second durations, such as quickly checking a phone or Blackberry wireless device for a message. We sought to minimize the possibility of missing such interactions in this study.

Therefore, despite its increased costs in time commitments, we chose direct in-person observation to gain insights into the routine, everyday usage of technology in meeting situations. Participants in both study sites felt comfortable with an individual residing inside or immediately outside of the meeting space to take observations with the caveat that the observer would leave the space when asked to. Furthermore, if the observer was outside of the space, privacy could be obtained simply by closing the door. The door was not closed on a frequent basis; on one occasion the observer was asked to leave the project room while an employee review was conducted, and on three occasions, the observer arrived to the conference room to find the door closed.

We recorded interactions with technology, both room-based and personal devices, and time-stamped each observation along with the context of usage. To supplement this data, we took pictures with a digital camera (and did not use a flash). During post-study interviews, all individuals indicated they were unaware that pictures had been taken.

3.5 Preliminary Observations

Preliminary observations of the Alpha Corp. space indicated different patterns of occupancy. Managers often used this room in the morning to respond to emails, conduct staff meetings, or work individually. Occupancy in the afternoon was variable; individuals presumably traveled to plants, conducted off-site meetings, or resided in the open spaces of the building.

Preliminary observations of the Beta Corp. space occurred when the space was scheduled and did not conflict with observations occurring in the project room. However, this conference room was not utilized consistently nor often. Workers reserved this room (according to the online schedule system) about 25% of a typical workday. However, the room being reserved did not necessarily result in the space being used; on several occasions, individuals arrived to find someone else in the space using the phone. Instead of interrupting, attendees would find another open room. In addition, several meetings were canceled or rescheduled and the reservation was not pulled from the scheduling system.

3.6 Intervention

Halfway through the eight-week observation process, we placed a second large display into each space. We wished to examine whether routines would generally change with the presence of new technology, or perhaps if individuals would adapt technology use to further support existing routines.

We connected the second shared display to an off-the-shelf video switch (ATEN 8-port), allowing the display to be used by multiple individuals. We left the original large display in each room untouched, using the video switch only on with the second display in part to investigate whether multiple individuals would connect to the display. We specifically chose the ATEN video switch due to it being readily available and requiring minimal training for use. We acknowledge researchers have built several software-based systems, but none of these are widely adopted, so we opted to use a commercially-available product.

We placed a 37" LCD display running at a native resolution of 1366x768 into the project room and a 46" LCD display running a native resolution of 1920x1080 into the conference room (the largest sized displays that would fit into each room). For consistency, the second display might have been identical to the primary displays, however since both spaces used tabletop projectors, we used LCDs as the secondary display to minimize extra heat and noise at the table level.

Figure 13: Reoriented projection surface in project room at Alpha Corp.

An additional intervention occurred in the project room at the start of the observation period. Several deficiencies appeared in the space complicating the display intervention. First, we were concerned that lack of a resident projector would result in the second display being used as a single, primary display, and individuals would not borrow the projector as they typically would. To ameliorate this concern, we added a dedicated projector into the space.

Second, attendees used the white board as a projection surface, resulting in excessive glare and significant loss of usable surface area. When probed about this, attendees indicated it was the only surface that did not have other materials on it; the only empty wall space was the glass wall, which was not suitable to project onto. To free up the marker board (and, as an added bonus, make it easier to place in a second display), we cut a piece of foam core and placed it on the glass surface. Participants could use this piece of material as a projection surface (Figure 13).

3.7 Findings

In total, we observed 15 meetings in the project room pre-intervention with 17 meetings observed post-intervention. In the conference room, we observed 6 meetings pre-intervention and 9 were observed afterwards. We report on device usage, both personal and room-based, for the project room and conference room, as well as the types of tasks we observed individuals performing. We also analyzed field notes, pictures, and interviews using inductive coding and group together findings under emerging themes later in this section.

3.7.1 Meeting Tasks

Table 3 reports observed tasks observed occurring in each meeting space, categorized using McGrath's task framework. Note, however, that the number of tasks observed may be larger than the total number of meeting observed because many

Table 3: Classifying observed meetings via McGrath's framework. Results are listed on a per meeting basis, categorized pre- and post- display interventions.

	Alpha Corp. Project Room		**Beta Corp. Conference Room**	
	Pre-	**Post-**	**Pre-**	**Post-**
Type 1: Planning tasks	9	12	4	4
Type 2: Creativity tasks	3	4	2	3
Type 3. Intellective tasks	4	5	2	3
Type 4: Decision-making tasks	5	2	2	4
Type 5: Cognitive conflict tasks	7	9	5	6
Type 6: Mixed-motive tasks	0	0	0	0
Type 7: Contests/battles/competitive tasks	0	0	0	0
Type 8: Performances/psycho-motor tasks	0	0	0	0
Total Meetings Observed:	15	17	6	9

meetings had more than one task occurring. For example, in the Beta Corp. conference room, we observed two individuals conducting a Web site review of one of the company's products. This meeting consisted of a mix of generation of ideas, generation of plans to execute those ideas, and also resolving conflicting points of view between customers, dealerships selling the product, and the company itself. Thus, this meeting represented a mix of planning, creativity, and cognitive conflict tasks.

Recall that Fjermestad and Hitlz reported that 52% of studies evaluating GDSS's designed to facilitate collaboration used *decision-making tasks* in their methods where there is no definitive answer or objective measure of quality. Furthermore, the authors note that second most-popular tasks used in GDSS studies were *creativity* tasks, such as brainstorming sessions (Fjermestad and Hiltz 1998). Our findings, as illustrated in Table

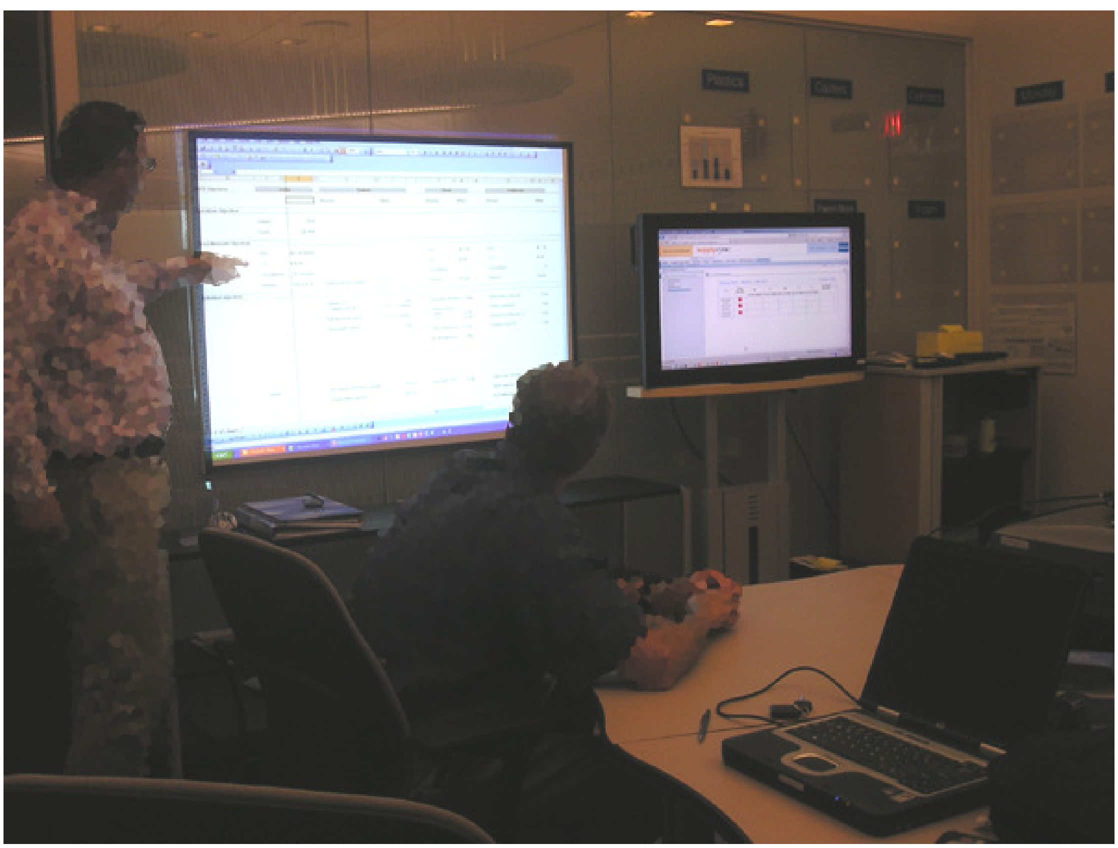


Figure 14: Project room employees using both displays for a sensemaking activity.

3, illustrate that meetings in these companies consist of a variety of the tasks classified by McGrath, many meetings consisting of more than one task.

In particular, we noted a *sensemaking* activity occurring in both meeting spaces; project room attendees performed sensemaking tasks ten times throughout the observation period while conference room attendees performed a sensemaking task on three occasions. Figure 14 illustrates an example of a project room meeting in which both shared displays were used for a sensemaking activity.

In a sensemaking activity, meeting attendees investigated some sort of event or phenomena that was confusing or unclear. Sensemaking involves a group or individual realizing their knowledge and understanding of events, concepts, or data, is incomplete or inadequate (Klein, Moon et al. 2006). Sensemaking is an active process where new data is used to create new conceptual models of phenomena or events. Individuals then use these conceptual models to find relationships amongst the data. Thus, sensemaking primarily combine aspects of creativity, intellective, and decision-making tasks. In cases regarding product development and sales, sensemaking activities often transition into planning or creativity tasks once an understanding of the event or phenomena is reached.

We also note the occurrence of *cognitive conflict* tasks within both meeting rooms. As global companies, Alpha and Beta Corp. have relationships not only amongst co-located coworkers, but also amongst suppliers, vendors, manufacturing plants, and coworkers in the field. We observed that meeting participants often would bring up the goals and needs of other entities during meetings, especially regarding Alpha and Beta Corp.'s sales dealers.

The wide-range of tasks we observed within each meeting space (i.e. Table 3) further supports Huang *et al*'s claim that large displays within meeting environments need to be flexible in the tasks they support (Huang, Mynatt et al. 2006). Furthermore, as we describe in the following section, individuals used different technologies to accomplish the same goal, such as preserving whiteboard contents. Thus, our findings reinforce the observation that collaborative spaces ought to support a wide-range of users and tasks.

3.7.2 Summary Statistics

We recorded statistics on technology usage during the meetings, as shown in Table 4 and Table 5. Note that throughout all meetings, many attendees were repeat technology users. In addition, we recorded the number of discernable remote attendees who participated in the meeting via speakerphone.

Table 5 shows the frequency of meetings where personal devices were used at least once during a meeting. We refer to *usage* as when an individual manipulated the device's interface to send, receive, or view information. Examples of device usage include typing an email on a laptop computer, checking missed phone calls, or sending a text message.

Every meeting in the project room had at least one personal device used. The conference room also had a very high-rate of device usage with 88.9% to 100% of meetings observed having at least one personal device brought in and used. In the conference room, on the average, 62-65% of attendees had a personal device used it.

In addition, Table 5 shows a breakdown of the average number of attendees who used laptops, phones/PDAs, and paper/pens in meetings. Meeting attendees most frequently used laptops, used by 73-88% of attendees in the project room, and by roughly half (51-55%) of conference room attendees, on average. Although different user populations were observed and a formal comparison is inappropriate, our results highly conflict Newman's findings, who reported devices infrequently brought into the conference room. Many reasons can account for this difference, such as organization culture, personal attitudes towards technology, or simply the increased proliferation of portable devices and wireless Internet since the Newman study was conducted.

Table 4 reports a breakdown of room-device usage, indicating a variety of devices were used in both spaces. Attendees used the projector and conference phones most often, and only used whiteboards occasionally. In the conference room, users engaged the whiteboard capture system only once. Interestingly, we observed two individuals use their cell phone cameras to capture whiteboard contents, rather than using the built-in system. We discuss the preservation of whiteboard contents via cell phone camera in more detail in the next section.

Table 4: Frequency of room-based device usage.

Phase			***Number and percentage of meetings where….***				
		Meetings	**Projector Used**	**Secondary Display Used**	**Conf. Phone Used**	**White Board Used**	**Copy Cam Used**
Project Room	Before Intervention	15	7 (50%)		9 (60%)	4 (27%)	
	After Intervention	17	12 (70%)	9 (53%)	6 (35%)	7 (41%)	
Conf. Room	Before Intervention	6	4 (67%)		2 (33%)	2 (33%)	0 (0%)
	After Intervention	9	4 (44%)	2 (22%)	4 (44%)	4 (44%)	1 (11%)

Table 5: Frequency of personal device usage during meetings.

Phase		Atten dees	Remote Attend-ees	People w/ Personal Devices	Mtgs w/ at least 1 device	Lap-tops	Phone PDA	Paper/ Pen Usage
Project Rm.	Before Intervention	41	5	100%	100%	88%	39%	67%
	After Intervention	56	3	100%	100%	73%	55%	39%
Conf. Room	Before Intervention	23	2	65%	100%	55%	10%	65%
	After Intervention	40	8	62%	88.9%	51%	16%	86%

We noted different usage rates of the secondary display across the two meeting spaces. The project room users engaged the secondary display in roughly half of the meetings observed, while the conference room users engaged the secondary display twice out of nine meetings. To explore usage habits, we conducted interviews as well as analyzed our field notes using inductive coding to capture usage themes regarding the shared display usage routine, which we present in the following section.

3.7.3 Qualitative Findings: Technology Routines

3.7.3.1 Information Sharing Routines: Shared Displays.

Prior to the addition of a second shared display, project room attendees at Alpha Corp. used the projector 50% of the time. The type of information shared on the shared display ranged from spreadsheets, internal documents, internal company Web pages, to sharing contents of an individual's email with the larger audience.

We observed three distinct routines regarding how Alpha Corp employees used the single shared displays. First, employees used the single display for traditional presentation of material, such as an individual giving a PowerPoint presentation. Second, users used the single shared display as a common display to jointly work on a document. We observed users jointly create performance metrics and develop an electronic version of a paper-based tracking system. Finally, we observed a routine where an employee would use the shared display to broadcast what he or she was individually working on to other individuals in the room who were working on their own tasks.

This routine of publicly displaying information generally occurred when two or three individuals were in the space working on individual tasks but still communicated intermittently with each other, where essentially a group of employees were "alone-together" (Ducheneaut, Yee et al. 2006). One user would remain connected to the shared display after collaboration and continue to leave the projector running, thereby allowing others to maintain a sense of awareness of what the individual was currently working on. Other users would look up from their individual work intermittently and comment on the publicly-shared content.

Once the second shared display was placed into the project room, we observed Alpha. Corp. employees adapt the existing three display routines to utilize the new display. After the display intervention, the projector was used in 70% of meetings while the shared secondary LCD display was used 53% of the time. We observed similar content being shared as prior to the display intervention. Traditional presentations used the main projector while the second display was typically kept off. However, we note two occasions when the second display was used to keep track of changes to current projects, acting as a peripheral information display.

The routine of using shared displays as common targets also adapted to the presence of the second display. In particular, the second shared display enabled direct comparison of material during sensemaking tasks as well as peripheral information monitoring. We noted six occasions when individuals appeared to be performing sensemaking activities; Figure 14 shows a picture of Alpha Corp. employees using both displays to perform one of these tasks. Furthermore, we observed four meetings where an individual presented material on one shared display and another individual would place supporting or reference material on the second display. This act of sharing information via shared display occurred instead of an individually verbally summarizing content from their computer or turning their laptop around to share a view, as was done prior to the display intervention. Finally, we observed users adapt the public display routine for multiple shared displays. We observed eight instances where two individuals maintained public broadcast of their laptops via shared displays while working individually.

While project room shared display usage went up after the display intervention, the conference room projector usage went down from being used in 67% of meetings to 44%. Beta Corp. employees used the shared second display only twice, one of which it was used as the sole display to present material. There were several occasions though, that the secondary display was turned on out of curiosity but was never connected to a source. By-and-large, existing routines did not change or incorporate the new display.

In the conference room, Beta Corp. employees displayed content on the primary projector ranging from spreadsheets, Web pages, and annotated digital images. We observed two meetings in which the company president used the main projector to display elaborate spreadsheets with integrated charts (referred to as "Dashboards") of product sales. The company president then alternated between displaying the Dashboard and showing other material. We observed participants use the shared display for traditional presentations as well as collaboratively working on documents or tasks, notably reviewing the company's Web site on various products lines.

During post-study interviews, we asked conference room attendees about the relatively low usage of both the room-based projector and the second shared display. Attendees attributed the lack-of-usage towards a combination of perceived technological glitches (discussed later in this section) and that the VGA cable was physically distant from many of the seat locations. This reiterates a key finding from the iRoom project (Johanson, Fox et al. 2002) where researchers concluded users should have control of displays from their seats.

3.7.3.2 Information Sharing Routines: Static Information Displays

As noted earlier, users of Beta Corp's project room used wall space for persistent information displays of charts, posters, and post-it notes. One main goal of this was to provide at-a-glance awareness of issues and project status. A Beta Corp. employee explained the benefit of these displays is that while a meeting progresses, one can immediately change the status on the board in view of others present. We note that static information displays facilitated peripheral information monitoring. Furthermore, one employee remarked that physically updating a chart on the wall seemed to offer a visceral connection:

> "*There's something satisfying about actually going up to the chart and updating it or taking an item down when we complete a part of a project*."

However, we observed a change in this routine due to the introduction of the second shared display. One manager remarked how she and her team were experimenting with moving the accountability board from the physical walls onto the second shared display, allowing this material to be accessible to other team members who are not in the space:

> *"I'll call up a set agenda topic on the mains screen and then someone puts up the electronic accountability board on the other one. So when something comes up, someone can type in what person is supposed to do that…[it was] very helpful."*

The conference room at Alpha Corp. did not have static information on the walls due to its shared nature. However persistent information did appear to be relevant at meetings, but occurred in the form of paper handouts. 67% and 37% of pre- and post-display intervention meetings, respectively, had some form of paper handouts given to meeting participants. These handouts were typically meeting agendas or reference material.

3.7.3.3 Information Sharing Routines: Whiteboards

In both the conference and project rooms, we observed regular use of whiteboards, approximately in 34% and 40% of meetings, respectively. Attendees in both spaces used whiteboards for sketching concepts, scheduling, and conducting brainstorming activities. In Beta Corp. meeting, participants placed Post-It notes on the whiteboard during a brainstorming activity and used markers to annotate concepts. Thus, we note whiteboard usage because it represents an analog shared display for users within each meeting space.

We did not observe individuals in the project room attempt to capture whiteboard content. However, Alpha Corp. employees used a section of the whiteboard to schedule occupancy of the space. This area of the whiteboard was not marked explicitly for preservation, however there was an implicit knowledge amongst the individuals sharing this space to not erase this part of the board.

Conversely, we observed two meetings in Beta Corp's conference room where individuals wanted to capture content on the whiteboard. In one instance, the attendee used the installed capture system. In the second meeting, the organizer could not figure out how to use the whiteboard capture system and simply wrote, "Do not erase!" next to the content and went to lunch.

However, the next group of individuals using the conference room wanted to use the whiteboard to tweak the industrial design of a product. They recognized the handwriting of the "Do not erase!" comment and attempted to contact her via cell phone. Unable to reach her, they debated about how to preserve the content on the board. Ultimately, one attendee used his cell phone camera to take several pictures of the whiteboard and email the pictures to the required person. When we asked why he used his phone versus the built-in system, the attendee explained that he knew exactly how his phone worked and was not quite sure how the capture system in the room worked. He stated that spending the time to figure out how the system worked and where captured images were stored would have hindered getting his meeting started, and therefore it was not worth doing.

3.7.3.4. Personal Device Routines: Laptop Computers and Cell Phones.

Laptops. Shared display usage is part of a larger ecology of people, devices, and information. Individuals frequently brought and used devices into both meeting spaces, as noted in Table 5. Approximately 75% of the time an individual connected a laptop to a shared display in either space, the physical connection between the VGA cable and laptop was made within the first five minutes of entering the space. The initial arrival of an individual within a meeting room was frequently social in nature when individuals would engage in small talk, asking questions regarding the personal lives of other employees. As Poole et al note, meetings are a continuing negotiation between the social-needs of the group and performing meeting-specific tasks (Poole, Seibold et al. 1985). Thus, the time period associated most often with connecting to a shared display was social in nature; we explore this in more detail in the Section 3.9.

In remaining instances, we observed users connect to the shared display(s) as necessary. For example, in the project room space, before the display intervention, we observed individuals to occasionally leave the projector on in the default blue-screen mode while occupants worked individually. When an individual wanted to share content, he or she would reach for the VGA cable at the center of the table and connect their laptop to the display.

Project room attendees brought in and used laptops about 88% of the time prior to the display intervention and 73% afterwards. Laptop usage occurred in intervals within the project room, perhaps attributed to the mobile nature of group members, as well as the overall feel of the project space as a "war room." In fact, the project room often seemed to transform into a shared office. We observed instances of Alpha Corp. employees working "alone-together" (Ducheneaut, Yee et al. 2006), where each person sat around the table working either individually or in pairs and occasionally would share information with each other. The alone-together type of meeting was viewed as a great asset to individuals, as one articulated:

"*I feel like you can get more done in here than in the open area. If you have a*

Blackberry, you're mobile…you do not have an office or desk. I do wander. But, when we're all in this room together, we can answer things quickly to each other so we can get a lot more accomplished that way rather than waiting for someone to respond to an email."

During these alone-together meetings (i.e. Figure 11), we observed that laptops were almost always open in front of attendees where individuals were actively engaged in an activity (typically email). When more traditional meetings were held in the project room space, we observed that laptops generally remained open so attendees could more closely examine documents or internal company Web pages to gain additional detail.

We also observed a high laptop usage rate in Beta Corp.'s conference room; 55% of all meeting attendees used a laptop at least once during a meeting before the display

Figure 15: Signaling via keeping laptop partially open.

intervention and 51% did so afterwards. Laptop usage, except for individuals presenting information via projector, was largely episodic. Individuals who brought their laptops into meetings often kept their laptops partially closed (Figure 15) for a majority of the meeting, then quickly check and respond to email, and then return the machine to a semi-closed state.

During interviews, several people indicated that the half-closing of the laptop gesture is a signal to the speaker of respect, indicating that the attendee was paying attention to the meeting. By keeping the laptop ajar and not shut, users claimed it took less time to check email since the user would not have to re-authenticate. Still, we also observed other individuals keeping their laptops closed completely, only to open up and check email or locate information, and then close the laptop again. We only observed one individual in Beta Corp, not presenting information, who used his laptop computer the entire time someone else was leading a presentation.

Every employee interviewed at Alpha and Beta. Corp talked about the need to stay on top of email as part of their job, and how social protocols impacted the choices they made on using laptops during meetings to check for email. In particular, one individual remarked:

> "*I think a lot of people feel very swamped at meetings like this—and I don't want to take anything away from it—but it [the meeting] might be a little less important than other things on their plate. They think, 'If I bring it in where I can do this and get it done during the meeting—since parts of the meeting won't apply to me.*"

Another conference room attendee remarked that she was extremely busy and for her to be away from her desk for an hour-long meeting was difficult, so she would check her email periodically during the meeting to see if there was a critical issue she could address quickly, virtually being in two places at once.

Cell Phones. Both Alpha Corp. and Beta Corp. provided technical infrastructure for employee cell phone use by issuing company phones to employees, but also installed cell signal repeaters within the buildings to increase coverage. Several interviewees remarked that mobility was inherent with their positions, and that being able to be reached by team members via cell phone was useful to bridge the physical gap.

We observed that cell phones were almost always brought into each space, representing another object competing for users' attention, although whether participants actually used their phones varied from space to space. We observed at least one individual making a phone or take a phone call within half of the meetings within Alpha Corp.'s space, in contrast to only 13% of Beta Corp. Alpha Corp. employees used their phones to quickly obtain information about suppliers, plant issues, or other manufacturing questions and relay that information to other individuals, update a static display on the wall, or enter information onto a laptop computer.

3.7.3.5 Technology Failures and Recovery

We observed hardware and software glitches in both spaces regarding the shared displays. In the project room, one attendee accidentally bumped a power strip, turning off power to both of the large displays. In the conference room, a defective VGA cable resulted in a shimmering image on the projector. We observed that hardware failures such as these were self-diagnosed and resolved quickly and individuals shared a laugh over the mishap.

One notable technology failure at a Beta Corp. meeting involved sharing a spreadsheet from the conference room to a remote-location by using company-provided commercial collaboration software. For this meeting, we observed an employee arriving early to set up and coordinate the information sharing session with his counterpart at the remote site. Upon successfully establishing a remote connection on the shared display, the employee left the room to get a cup of coffee and returned to find the connection had terminated. As the only software troubleshooting method they knew, employees on both ends tried to restart the collaboration software and subsequently each of their computers to re-establish the connection. When these troubleshooting steps did not resolve the problem, the employees resorted to placing the spreadsheet file on a shared network drive and use the conference phone to give directions on where to navigate within the document. During interviews, attendees noted that this type of struggle with software was not irregular:

> "*That happens all the time. We put it [a file] onto the S drive and tell them [the remote party] to go there and take a look at it. We don't know if they are doing it then and there, or going and looking at it later. That's a classic case of technology interfering because it's not working right.*"

In particular, Beta Corp. employees mentioned this one specific incident on four occasions during interviews. Individuals expressed apprehension about using software solutions due to distrust in software from poor prior experiences and also a lack in confidence about being able fix problems in a timely fashion. Furthermore, one interviewee mentioned the comfort of existing routines as being a chief barrier for adopting any new software within the organization, even a software-based display sharing solution:

> *"People are very comfortable when they go into the room and they know where to plug in, power on, and push the function key on the laptop and up comes the laptop [to the screen]. A lot of people don't want to have to download software to do something new."*

3.8 Cognitive Framework Interpretations

As was noted in (O'Connor 1980), the meeting process varies considerably from meeting to meeting, group to group, as well as the meeting progresses. We argue that by understanding some of the commonalities amongst the two environments presented in our field studies allows for insight into how meeting spaces support collaboration. For example, across the two meeting sites, we observed three distinctive styles of meetings:

-**Leader-led** where one individual acts as the meeting facilitator. The role of facilitator, generally speaking, was to make sure the meeting stayed on task and solicit participant or feedback from the other individuals as necessary. The degree to which the facilitator controlled the meeting process varied from meeting to meeting, individual, to individual.

-**Self-negotiated** where a small number of attendees (four or fewer) and actively participate and there is no clear meeting facilitator. An example of this style of meeting occurred when two Beta Corp. employees meeting in the conference room to review the information listed on a product Web page, or when Alpha Corp. employees were performing a sensemaking task.

-“**Alone-together”** (Ducheneaut, Yee et al. 2006) meetings where individuals would primarily work on their own tasks and periodically ask a question of another person.

RQ 2 asks, "*Can a second shared display result in an improvement in the meeting experience, or is it a distraction?"* Since Beta Corp. employees did not adopt the second shared display, we focus on examining how individuals within Alpha Corporation used the shared displays for each of these styles of meetings. However, we do explore reasons why the second shared display was not used in more detail in Section 3.8.

During alone-together meetings, we observed Alpha Corp. individuals publicly broadcast their individual work. Self-negotiated meetings, mainly ones involving sensemaking activities, typically used shared displays to explore or compare information. During leader-led presentations, one display was used to show the presentation and the second display was kept either idle or showing information of a peripheral nature (i.e. the electronic accountability board). Alpha Corp. employees stated during interviews that the second shared display was not distracting even though it placed more information into the room.

The cognitive frameworks discussed in Chapter 2 allow us to explore why participants in Alpha Corp's project room indicated during interviews that the second shared display was not distracting or increasing their workload. Furthermore, these frameworks afford insight into potential challenges faced by users of multiple shared displays in environments that include multiple devices and individuals.

Wicken’s Multiple Resource Theory (Wickens 1980), as applied to leader-led meetings, acounts for how attention is allocated between speakers, shared displays, and personal devices. Typically, we did not observe prolonged multitasking of individuals during leader-led meetings (except for one individual noted earlier) due to the perceived rudeness in doing so. Multi-tasking typically occurred in short durations as a "necessary evil" to stay apprised of other situations within the organization. We do note, however, two Beta. Corp. employees who indicated that they did not use laptops at all during leader-led meetings because they felt they could not devote the attention required of both participating in the meeting and undertaking a secondary task.

Wicken's Multiple Resource Theory model proposes that humans do not have one single information processing resource, but several resources that can be used simultaneously, if different tasks do not require the same resource, such as auditory modality processing. Instances of leader-led meetings can heavily rely on both visual and auditory modalities to convey information to the group, such displaying and discussing the contents of information "dashboards" (product sales, manufacturing costs, and other data combined into one chart). Therefore, an individual multitasking on his or her laptop adds a second visual modality task for participants and MRT predicts excessive workload conditions will occur.

Furthermore, MRT predicts why using a second shared display to perform a peripheral information monitoring task will not distract from the presentation of information on the main projector during a traditional presentation. For peripheral information monitoring tasks, MRT states that the primary projector is focal in nature, while the peripheral information on the second display is ambient in nature. Since these two channels are not conflicting, MRT does not predict excessive workload.

We observed the second shared display being used for self-negotiated collaborative meetings where the second display was actively used at the same time as the original display, for example when groups were comparing information during sensemaking tasks. In this instance, the presentation of two visual streams from each display did not interfere with each other, as MRT would predict. We hypothesize the lack of interference is due to two shared displays' proximity to each other, and each display's content are combined as a single source of visual information for users to perceive and process. Future work can use eye tracking to explore this phenomenon in more detail.

We also note that BlackBerry wireless devices were also part of this information ecology. Individuals set their BlackBerries on vibrate, therefore the notification of new email, messages, or phone calls did not interfere with the main meeting tasks occurring in visual and auditory modalities (via MRT). Individuals would consult their devices during gaps in the meeting and then return attention to the main meeting topic.

Situational awareness explains the success of the alone-together style of meeting at Alpha Corp. While employees worked individually, static and electronic information displays in the project room facilitated maintaining an awareness of other activities within the company, as well as those occurring immediately within the room. When individuals broadcasted their work using the shared display(s), they provided additional situational awareness cues for other people in the room. Individuals also reported during interviews that since they worked closely with each other in this space, they were able to read each other’s body signals, and use that information to determine when or how to approach another person, an example of projecting from previous experiences and events towards the future.

3.9 Implications for Design

The purpose of this longitudinal study was to examine the routines associated with how shared displays are used within existing meeting spaces at two companies (RQ1). In particular, we were interested to see if a second shared display resulted in an improvement in the meeting process (RQ2). We examined this in the context of established or implicit protocols, before and after a second share display was added to each space.

However, since so many variables can differ from organization to organization, and meeting space to meeting space, one might argue that it is inappropriate to draw comparisons. We argue that similarities across these two spaces can provide insight for understanding how individuals currently work and collaborate in multi-purpose spaces.

1. **Device arming occurs not only due to technology limitations, but also is intertwined with the social needs of the team.** According to our observations, the devices used by individuals within the meeting room follow a standard lifecycle of the device:

1) arriving into the space

2) being retrieved by its user

3) being armed

4) being used

5) being put stowed away

6) leaving the space.

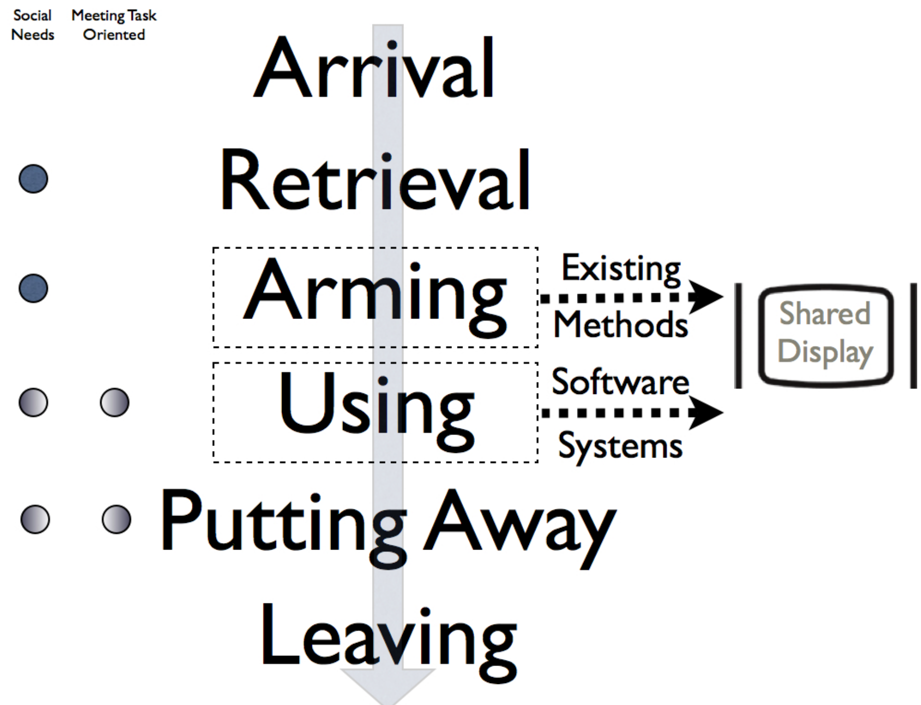


Figure 16: Display/device lifecycle in the context of social-needs and meeting tasks.

Figure 16 illustrates this lifecycle with respect to when devices connected to shared displays. We also characterize this lifecycle in the context of Seibold and Poole's findings that meetings are a balance between meeting tasks and the social needs of the collaborative process (Poole, Seibold et al. 1985).

The majority of users start each meeting with a ritual that we term "arming" which is a process of often connecting a power supply, plugging in a network cable and/or mice, and if presenting, also connecting to a shared display. In addition, individuals placed paper-based resources such as a notebook or printed handout on the table next to them.

The physical tethering of electronic devices is a result of both limitations of technology in real-world applications as well as social routines. Laptop batteries may simply not provide enough power for a meeting and wireless signals may often drop out or provide slower data speeds than a wired connection. In addition, arming is part of the process of individuals nesting and defining personal spaces at a shared table as well as interacting with others. This does not appear to be disruptive, since individuals often take advantage of the relatively low cognitive load of the physical act of plugging in cables to socially engage with other individuals, allowing for a transition into the meeting domain. In every meeting, we observed individuals engaging in small talk while arming their devices. It is important to note that meetings are more than simply the dissemination of information; there are also aspects of power relations and social relationships. Thus, an implication for new meeting technology is to examine the point at which designers integrate the connection component to displays in meeting environments, shown by the arrows in Figure 16.

In our fieldwork, we observed a vast majority of participants connecting their devices to the shared displays during the arming phase of the personal device usage lifecycle—a mundane and routine act that is visible to other attendees. Other studies, such as Newman *et al.*, offered a software infrastructure to support connecting to a VGA projector, but did so at the "use" level where a device is already powered up. More research is needed to explore whether creating display connections at the use level impacts usage—it is not clear that software display sharing techniques facilitate the social aspects we observed involved with the arming process.

HCI often concerns itself with the artifacts of computer mediation in a mainly technological environment. Designers should take care to not fundamentally change interaction models such that interaction is driven by technology rather than technology facilitating interaction. The six-step model portrayed in Figure 16 categorizes device/display usage in real environments. We argue that analyzing *when* to make the connections is important in hybridizing existing meeting spaces with technologies that can support it, rather than using a technology to fundamentally alter the mediation. In the previous section, we report instances where individuals did not use or quit using technology because they felt they were fighting against it versus having the technology support their collaborations. Furthermore, we report instances where users opted to use the second display since it enhanced information routines already in place.

2. **Ephemeral personal device usage.** Anecdotal evidence suggests multi-tasking is quite common in academia. Of the 505 attendees at the CSCW 2008 conference, for example, 305 devices were actively using the wireless Internet connection during a one-hour period (Begole and McDonald 2008). Likewise, in our two observation sites, we noted frequent multi-tasking during meetings. However, we observed very different patterns of multi-tasking occurring both across and within each of the two observation sites. Both the project room and conference room attendees frequently brought in laptops and cell phones to meetings. In the project room, for example, individuals often worked on another task in parallel to another meeting activity during self-negotiated meetings, thus multi-tasking episodes were often longer in duration. In the conference room, however, most device usage was very short-lived aside from a presenting individual being connected to a display to share information.

We report that this ephemeral usage occurred as a result of the social relationship amongst meeting attendees in this space. During interviews, it was often viewed as being disrespectful to be typing away during another person's meeting or presentation. However, interviewees acknowledge that staying on top of email is a necessary evil because being away from their desks for long periods of time could result in potential costs for the company. Therefore, as a compromise, email checking occurred, but not at a regular basis. Individuals closed or lowered laptops during meetings as a way to signal engagement to other attendees (Figure 15). Furthermore, this type of ephemeral usage also appeared within the project room when more formal meetings were occurring, rather than the “alone-together” types of meetings.

Ephemeral device usage is an important implication for co-located collaborative technology designers. One cannot assume that every meeting attendee will have his or her devices at the ready, with a data connection established, for the entire duration of the meeting. When developing software infrastructures, designers also need to account for the possibility that devices may be offline and require being powered on, software reinitialized, and IP addresses reassigned. These processes result in additional time required for a user to get up-and-running and may present a significant barrier for adoption. We note that both observed populations were wary of using technology that creates a perception of slowing down the meeting process. One such instance was a meeting participant using his cell phone to capture whiteboard contents instead of investing time in learning how to use the provided capture system.

3. **At-a-glance (peripheral) information is important**. Interviews indicated one of the most important features of the project room was the ability to use wall space to display at-a-glance awareness of projects, issues, and status (Figure 11). Likewise, we noted meetings in the conference room often included paper handouts. These observations correspond to Huang’s discussion of the importance of at-a-glance information to groups (Huang, Mynatt et al. 2006). Therefore, it is not surprising that the

project room groups used the shared display on a frequent basis, since they performed very information-rich work. Furthermore, we noted that the project room employees explicitly used the second shared display during three meetings as a peripheral display, showing an electronic version off their accountability board system. However, at-a-glance information was also important to conference room attendees, but due to the non-owned status of the room, this information transformed itself into portable handouts versus using wall space.

Idle large displays within the project room space represented an opportunity to provide additional at-a-glance information of awareness. For example, performance metrics are captured and reported daily on internal Web pages within Alpha Corp. This information can easily be placed on an idle room display to increase awareness of peripherally relevant information. The ambient display and peripheral display research community within HCI offers evidence that information can be pushed into environments in non-distracting and visually interesting ways (Plaue and Stasko 2007).

4. **Physicality comforts and reassures**. The act of plugging in one's laptop to a VGA cable allows both physicality for connecting to displays and a way for users to visibly communicate to others. Individuals remarked that having a physical connection has a comfort factor; they know when their machine is unplugged they will not accidentally display personal information, avoiding a potential privacy pitfall. Likewise, reaching for the VGA display cable signals to other attendees the intent to use a shared displays and attendees can subsequently adjust their seating, laptops, and positioning to view the shared display.

This notion of physicality agrees with the importance of visibility pointed out in other areas of CSCW and HCI such as networking (Edwards and Grinter 2001) and air traffic control (Hughes, Randall et al. 1992). Furthermore, this also stresses the importance for technology designers to incorporate visibility of connectivity as they design both hardware and software mechanisms for the sharing of information amongst individuals.

Furthermore, physicality offers benefits for troubleshooting. In this study, we noted when individuals attempted to troubleshoot and resolve issues when encountering difficulties with the shared displays on two occasions. However, when software-related problems cropped up, individuals either attempted to solve the problem via restarting the computer, or else created workarounds. As designers create technologies intended for non-computer technical individuals, they should consider incorporating some physicality in their design to aid in trouble-shooting purposes. A challenge noticed both with iRoom and Classroom 2000 is the need to deploy these systems with a minimum of system administrators (Johanson, Fox et al. 2002). If formal technical support is minimal or nonexistent, mechanisms must be made to ensure that end-users can troubleshoot and remedy problems.

Furthermore, the ease of connecting to technology is important to users. A Beta Corp. project manager touched upon this during an interview:

> "*I try to hold short meetings, maybe 15-20 long. It's not worth spending 5 minutes setting up equipment or software for a meeting that will last 15 minutes.*"

However, physicality can lead to a sense of complexity. One individual in our study remarked that he felt the video switch was not used in the conference room space simply because the video switch and cables created a false-sense of complexity:

> "*[The goal is to avoid having] too much technology. You need it done neatly so folks can still feel comfortable and homey and still have good conversations amongst the technology [rather than having conversations about the technology]"*.

5. **Non-technical factors are critical for success for shared display usage**. Outside of the technology per se (i.e. "high tech devices"), the physical spaces themselves have important and under-appreciated impacts on meeting work and whether shared displays will be used. Some spaces, such as the project room, are owned resources and are treated much differently than shared spaces.

When technology designers research meeting spaces, they traditionally focus on the area of their expertise, such as software infrastructure, interactive displays, and technology services. Lighting, seating, and physical layout of the space also influence how people feel about the space. Obviously, if individuals do not enjoy spending time in a space, he or she is not likely to engage in any activities that may prolong the meeting experience. Individuals may have a choice in spaces, as the employees of Beta Corp did.

None of the individuals we observed and interviewed came from a computer science technical background. In fact, one advantage to studying user populations involved in the design and manufacturing of office furniture and environments is gaining additional insight into meeting space design. Beta Corp. employees commented that physical aspects of the room, such as paint color, lighting, and seating, influenced whether or not they chose to hold a meeting in that space, not necessarily the technology resources available within the space.

3.10 Field Study Conclusions

Research within the HCI and CSCW communities regarding collaborative technologies typically focuses on developing new infrastructures or interaction techniques. This work is important to the community as a whole because there are many everyday interactions that can arguably be improved, such as the experience of connecting a laptop to a shared display in a conference room, or making it easier to collaborate on a shared document.

Research such as the IMPROMPTU framework shows that there are benefits in developing software infrastructures to take advantage of multiple displays in a shared space. However, such systems target specific user groups for evaluation, such as software-development groups. Conference rooms, generally speaking, need to accommodate a wide variety of users, tasks, and meeting styles.

The field studies presented in this chapter uncover the technological, social, and information sharing routines that intermingle with each other throughout meetings (RQ1), impacting shared display usage. We report that individuals bring in laptop computers with them to either multi-task and maintain an awareness of other operations within the company (typically via email), and/or have information readily accessible for presenting. We did not discover evidence that the addition of a second shared display resulted in individuals bringing in more devices into the meeting space.

We also report on how multiple shared displays are effective in supporting certain types of tasks, namely sensemaking and peripheral information monitoring, and other situations in which users largely ignored the display (RQ2). We also report on routines common across both spaces, such as a ritual of arming devices. Furthermore, we report on how technology limitations and social routines come together to influence how and when individuals connect their laptops to shared displays.

CHAPTER 4

LABORATORY STUDY DESIGN

In Chapter 3, we described two field studies investigating the impact of a second shared display on the meeting processes during everyday operations at companies. We reported that the second shared display was rarely used at one company, but was frequently used at the other company, in particular supporting *sensemaking* and *peripheral information* monitoring tasks. A peripheral information monitoring task occurs when information displayed in a persistent manner in one's environment, consulted periodically by individuals while attention is primarily focused on another activity or display. Sensemaking occurs when individuals realize their understanding about some event, phenomena, or data is incomplete or inaccurate, thus requiring a need to assess new information and explore the relationships between data to create a new understanding of what is occurring (i.e. conceptual model).

In this chapter, we describe the design of an empirical laboratory evaluation investigating the effect of multiple shared displays on sensemaking meeting practices. Specifically, we want to examine how the presence and location of multiple shared displays can influence teams working on a sensemaking task. We define metrics of performance, collaboration, and satisfaction of the meeting process to evaluate the progress of the teams performing the sensemaking task. We simulate a style of meeting we observed in the field studies described in Chapter 3, where meeting attendees bring in laptops to share information with other attendees. During interviews, participants remarked that they brought their laptops with them to meetings in order to have information readily accessible.

4.1 Research Questions and Hypotheses

The goal of the controlled study was to evaluate the effects of *presence of* and *location of* multiple shared displays on a simulated meeting environment where individuals are performing a group sensemaking activity. We evaluate three different shared display configurations: single, dual side-by-side, and opposing dual displays (discussed in more detail in Section 4.3). In particular, our controlled study is exploring two research questions:

<u>*Research Question 2 (RQ2)*</u>

Can a second shared display result in an improvement in the meeting experience, or is it a distraction?

In this chapter, we explore RQ2 by constructing a controlled laboratory study examining whether dual-shared displays in meeting rooms increase the amount of information discovered (i.e. *key facts*) by a group performing a sensemaking task. Our study also explores whether dual shared displays in meeting rooms also increases the amount of logical links (i.e. *insights*) group members make between facts.

In this study, we examine three dimensions of the meeting experience: collaboration, performance, and satisfaction, as described in Section 4.6. We hypothesized that groups using multiple shared displays would identify more key facts and have more insights during their meetings than groups using a single shared display, simply due to being exposed to more data. Furthermore, we hypothesized the additional screen real estate provided by the second shared display will improve collaboration by providing opportunities to compare and contrast materials, a task fundamental to sensemaking (Thomas and Cook 2005). Finally, due to the second shared display introducing more information and a degree of interactivity for participants, we hypothesized that individuals in multiple-shared display conditions would be more satisfied with the collaboration process than those using a single shared display.

Research Question 3 (RQ3)

Can a controlled laboratory study effectively evaluate aspects of collaboration with respect to shared displays?

Groups of individuals interact differently with each other while collaborating, creating a challenging atmosphere to develop evaluation methodology to study performance. As we noted in Chapter 1, many studies evaluating GDSS's focused on two styles of tasks, mainly creative (i.e. brainstorming) and decision-making, where there is no definitive answer or objective measure of quality. In this chapter, we describe an insight-based controlled laboratory evaluation developed to explore RQ3 by objectively measuring the effects of the presence of and location of multiple shared displays when individuals are performing a nontrivial task, namely sensemaking. We observed sensemaking in our field studies as an activity facilitated by multiple shared displays. Furthermore, sensemaking includes several subtasks (i.e. creativity, decision-making, intellective tasks using McGrath's framework in Figure 5).

We acknowledge there are a plethora of different configurations, variables, and tweaks that could be tested and each of these variables may influence how displays are used. For the intents of this study, we sought to limit external variability as much as possible, focusing specifically on the three display configurations, and their impact on a

Table 6: Study participant demographic information.

		Single Display	Side-by-Side Dual Displays	Opposing Dual Displays
	Age in Years	24.0 (4.49)	22.41(2.79)	22.0 (2.85)
	Number of females	9	8	9
	Years of Education	16.4 (3.34)	15.1 (2.10)	15.7 (3.01)
	Hours Per Day Using Computer	5.8 (3.95)	6.7 (3.53)	6.3 (3.60)
Academic Majors	Computer-Related	22	23	21
	Industrial Design	1	1	2
	Engineering	6	6	7
	Social Sciences	3	3	2
	Biological Sciences	1	1	1
	Undecided	0	0	1
	Mathematics	1	0	0
	Non-student	1	1	1

team performing a task we observed occurring in real-world conditions. In this chapter, we discuss specific design decisions we made exploring RQ3 in creating objective measures to evaluate aspects of collaboration.

4.2 Participants

We recruited 105 individuals (26 female) to participate in the study. All but three individuals (a restaurant server, research scientist, and user experience engineer) were students at a technical university with an average age of 22.8 years (s = 3.53), as illustrated in Table 6. Sixty-six participants were in a technology-related major, such as computer science, computational media, or human-computer interaction, and other majors included industrial systems engineering (10), industrial design (4), biology (3), biomedical engineering (3), and psychology (3). Student participants received course credit for their attendance.

We randomly assigned individuals to a testing condition. The sheer number of participants required for this study made it impractical to find and use existing work groups. However, the relatively homogenous student population did remove a source of uncontrolled variance. Student participants were not likely to have adopted a particular style or meeting role, as might be common within established corporate or academic environments. Since participants did not know a majority of their group members, special measures were taken in the design of the experiment to ensure that all group members were familiar with the role of their teammates (as described later in this section).

4.3 Materials

We designed the study to simulate an environment in which participants bring in laptop computers containing information relevant to the meeting topic that is likely to be shared (Figure 17). The act of showing information via shared display is a ubiquitous and routine practice in both industry and academic meeting rooms (Newman, Ducheneaut et al. 2006). Our goal was to not replace the interaction of "showing data" via sophisticated

Figure 17: Simulated meeting room with six laptop computers, shared display, and whiteboard.

technologies, but rather to explore how multiple shared displays impacted collaboration. Three different configurations of shared displays were manipulated as the independent variable: single display, side-by-side dual displays, and opposing dual displays, as shown in Figure 18. We selected these configurations to not only investigate the effects of adding an additional shared display to the room, but also to explore the influence of location.

The shared displays were portable XGA projectors running at a resolution of 1024x768. For the multiple display conditions, we calibrated each projected image to be identical in physical size (approximately 1.2 meters diagonally). Due to the logistics of coordinating these sessions, we omitted a condition without any shared display, noting that many existing meeting spaces contain one shared display.

We provided each group with six laptop computers running only a fresh installation of Windows XP and Microsoft Office. Furthermore, we preloaded each laptop with a Microsoft PowerPoint presentation containing information required to solve

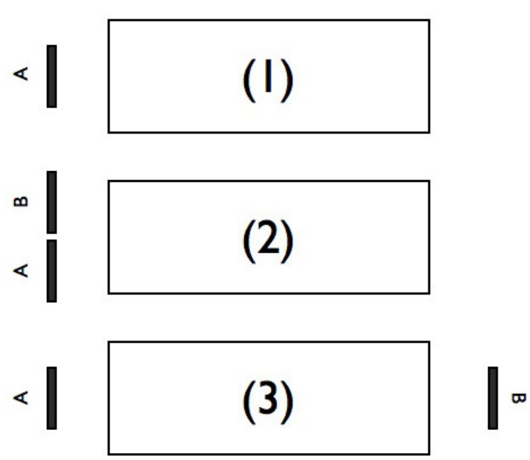


Figure 18: Three shared display configurations used in the controlled laboratory study: single (1), side-by-side (2), and dual-opposing (3).

the task (described in additional detail in Section 4.4). Each laptop computer was connected to an Altinex programmable video matrix switch.

Participants controlled the video matrix switch via a control box (Figure 19) placed next to each laptop. Participants shared content from their laptops by pressing a button mapped to a respective display. For example, the left button on a control box controlled the leftmost display, relative to the participant's position. We provided feedback to the user by illuminating the button, signaling which participant has control of a display. If a participant wished to no longer show content on a shared display, he or she simply had to press the respective control button a second time.

We acknowledge that several software-based solutions (e.g. (Newman, Ducheneaut et al. 2006)) have been built by researchers, however none of these systems are widely used outside of research lab applications. Therefore, we opted to use this off-the-shelf video switching solution. Also, the physical interface required minimal training and was easily learned by participants during pilot testing. Again, we sought to simply

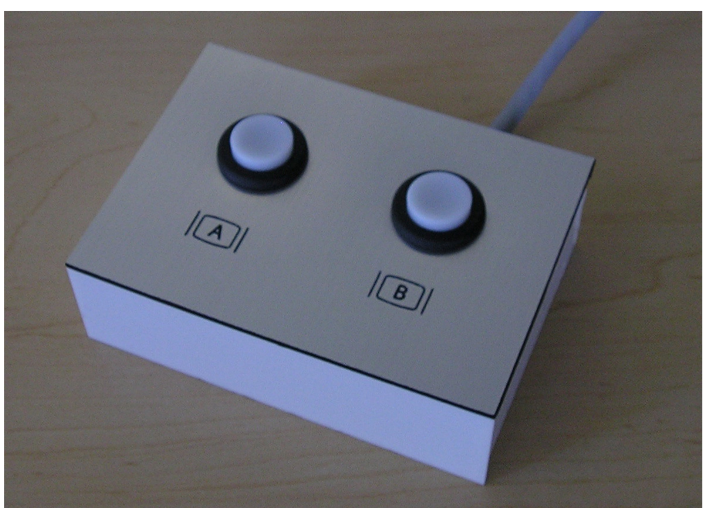


Figure 19: Custom-built control box hardware used to share content on the large displays at the testing site. Pressing the left or right button mirrors content from a participant's laptop on a shared display relative to the user's orientation.

provide a quick method for individuals to mirror the content of their laptops on the large shared displays.

We furnished the meeting space with a large conference table, six chairs (three on each side of the table), a portable white board, and two-level fluorescent lighting. The conference table seated a maximum of three individuals comfortably on each side of the table allowing for six participants per session. We kept lighting at mid-illumination to reduce glare and improve readability of the projector and provided participants with whiteboard markers, eraser, pens, and paper. Overall, we sought to mimic the ubiquitous conference room experience.

4.4 Primary Task

The collaborative task we used in our study is based on “The Bonanza Business Forms Company Case” (Jarvenpaa and Dickson 1988), used in evaluating a GDSS (Gallupe, DeSanctis et al. 1988). The scenario follows:

> *Bonanza Business Forms Company sells paper forms for three markets: small business, hospitals, and financial institutions. During the previous three quarters, Bonanza’s profits were steadily decreasing while total sales were increasing. Bonanza’s management cannot determine the cause of the declining profits, so they decided to bring you in as outside investigators. The goal of the outside investigation team is to determine the cause of the company’s problem using a series of reports, charts, and data to identify why the problem is occurring.*

We defined six investigator roles: domain researcher, industry trend analyst, sales force consultant, financial analyst, marketing consultant, and advertising trend consultant. Within an experiment session, participants were randomly assigned to a role.

For this study, we modified the original business case to create PowerPoint presentations for each investigative role. Data for the primary task consisted of bulleted information, charts, and graphs. To provide a sense of realism, we formatted the graphs to appear in the default Microsoft Excel font and color scheme (see Appendix A). Furthermore, each investigative role's presentation slides were unique, thus it was not possible to accurately discover solutions to the scenario without sharing information with other group members.

Pilot testing indicated the scenario was solvable, yet not trivial, requiring approximately 30-35 minutes for team members to reach consensus. Furthermore, pilot testing indicated the scenario did not require any specific management or business training to discover the solutions. However, we noted a potential problem resulting from the unfamiliarity of participants with each other. Team members would often lose track of who had each consulting role. A person might, for example, want to see information retaining to the advertising budget but forget which participant had the role of advertising consultant. To alleviate this problem, a colored band was incorporated at the top of each slide, coding and labeling each investigator role. Corresponding colored placards were placed on top of each participant's laptop. Therefore, a participant could recognize the owner of the desired material without having to remember the individual's name.

4.5 Procedure

We conducted experiment sessions with six participants (full team) at a time. Recall that a majority of studies evaluating systems facilitating collaboration (i.e. GDSS's) used fewer than five participants, even though prior research indicates assistive technologies are more beneficial to larger groups (Bui and Sivasankaran 1990).

Therefore, we designed our study to include the maximum number of participants the conference room table could hold, three participants on each side for a total of six.

However, due to the logistics in coordinating six participants, all three experimental conditions had one team in which a participant failed to show up. Rather than dismissing the remaining five participants, we chose to run those respective studies with five participants. We discuss these sessions in more detail later in this chapter.

Upon arriving into the meeting room, we randomly assigned participants to a laptop computer and administered informed consent and a demographic survey (Appendix B). The experimenter read an introductory script, outlining that the ultimate goal for the team was to determine why Bonanza's profits were decreasing while sales were increasing. The experimenter instructed group members to solve the problem using any strategy they wished, and also pointed out the whiteboard, paper, and video-sharing technologies. Furthermore, the experimenter emphasized that all the information needed to solve the scenario was provided in the PowerPoint presentations. Finally, the experimenter instructed participants that they could use any of the other built-in software applications such as the calculator or notepad programs, but also informed the participants that the computers were not connected to the Internet.

We instructed each group to hand in a list with their answer or answers to the business case dilemma as their final deliverable. To encourage groups to be thorough and efficient, we offered a $20 per person incentive to the group that solved the scenario most correctly in the shortest period of time.

Finally, after reaching group consensus, each participant individually completed a closing survey (included in Appendix B). The purpose of this survey was to obtain attitudes towards the meeting process as well as agreement with the group decision. After completing the surveys individually, we debriefed the study participants as a group.

4.6 Data Collection

We collected data via a combination of surveys, interviews, and video analysis. Furthermore, each experiment session was videotaped and later coded at one-second intervals to log events occurring during the sensemaking process, such as:

- identifying when and where information was displayed on the shared display(s)
- identifying when someone wrote on the whiteboard
- identifying who spoke when
- identifying when and who pointed to a shared display

We chose the 1-second sampling interval to fully capture ephemeral actions such as an individual pointing to a display or giving a short verbal response to a question posed by another group member. Furthermore, we transcribed the dialog of each meeting and the post-experiment group interview.

Yet, a challenge in acquiring this data was determining evaluation metrics. As stated earlier, we sought to evaluate group task performance in the various display conditions using the metrics of *performance*, *collaboration*, and *satisfaction.* Aspects of collaboration and satisfaction were probed through surveys and interviewing. However, establishing performance metrics was more challenging. Due to large variations in how teams of six individuals collaborate with each other, simply comparing the time to reach group consensus did not appear to an appropriate or sufficient method to evaluate performance. Therefore, we adopted a *key fact and insight-based* evaluation technique to evaluate team performance:

4.6.1 Key Fact and Insight-Based Evaluation Technique

In exploring RQ3, we developed an insight-based methodology to evaluate each group's collaboration, based on (Saraiya, North et al. 2005). Specifically, we sought to examine when individuals found key facts and drew correct inferences between the facts. Specifically, a *key fact* refers to a direct observation of data that is relevant to solving the dilemma posed in the primary task. Examining the number of key facts discovered by the teams offered a richer way of exploring collaboration habits than simply measuring time-to-completion (which was also captured) or the final group deliverable. The main challenge in using an insight-based method was establishing objective metrics over what constitutes key facts.

We consulted two individuals with formal business education training: a 29-year-old project manager with a degree in business administration, and a 30-year-old Masters in Business Administration student. Each individual read through the case study and

Table 7: Key facts for solving the task, as defined by two experts.

CAUSE OBSERVATIONS
Internal investigation points to marketing
Sales calls to healthcare sector high in proportion to other sectors
Number of accounts in healthcare sector high and growing
Total sales in healthcare sector are flat
Healthcare profits are low
Highest replacement percentage with magnetic media

MOST RELEVANT OBSERVABLE
Sales force compensation tied to commission on total sales
Healthcare field is very competitive
No competitive distinction / advantage between competitors

MINOR: ONE-OFF FACTORS
Pricing structure higher than industry average in healthcare
596 firms competing for 62% of total industry, 4 firms competing for 38%
Advertising costs high overall

Table 8: Insights defined for evaluating the performance of groups collaborating using the various display conditions.

Insight 1
Healthcare is seeing increased number of sales & the total healthcare revenue company-wide is flat → individual sales to healthcare are for smaller amounts.

Insight 2
Financial sector sales are seeing flat sales numbers & the total revenue from the financial sector is rising → individual revenue from sales to financial institutions are increasing.

Insight 3
The sales force is commission based & their commission is based on number of sales → the sales force is motivated towards sectors that have higher sales numbers.

Insight 4
The sales force size is unchanged & there are more accounts within the organization → the sales force is a limited resource that needs to be allocated efficiently.

Insight 5
Small business sales are profitable & sales towards small business sectors are relatively low compared to the other two areas → small business sales revenue is not contributing significantly to the company's financial health.

generated a list of key facts (Table 7) contributed to the primary reason for the decrease in profits at the fictional company. Since these ratings were highly correlated, we combined them to establish an objective grading rubric to judge accuracy, completeness, and thoroughness of each group's collaboration session.

To explore the breadth of groups' analyses, we defined five *insights* (Table 8), where groups correctly join two facts using logic (i.e. the number of sales for X remain steady [*fact 1*] while the total dollar amount of sales for X is increasing [*fact 2*] → the amount of each sale is increasing [*insight*]). These insights included primary and secondary factors influencing the fictional company's financial health.

4.7 Study Design Summary

The controlled study was designed to further explore the impact of the presence and location of multiple shared displays for teams of six individuals collaborating on a sensemaking process, an activity that we saw multiple shared displays facilitating during our field studies. We acquired data through surveys (found in Appendix B), interviews, and video analysis. Our video analysis of each testing session collected data at one-second intervals:

- identifying when information was displayed on the shared display(s)
- identifying who wrote on whiteboard and when this occurred
- identifying which team member spoke, and when they did so
- identifying when a team member pointed to a shared display

The one-second polling of data, accomplished by coding videotapes, allows for future extensions of this study. With additional technology resources, we can automate future experimentation by using microphones and cameras to capture information shared, verbal exchanges, and gestures. We also recorded times for the groups to reach consensus, not as a method of directly comparing team performance, but to standardize rates of groups observing key facts and making insights. We describe this in further detail in Chapter 6.

Our analysis of the data acquired from this study is discussed in Chapter 6 of this dissertation. However, the large amount of data collected from the video analysis required developing assistive technologies to explore relationships amongst the data.

CHAPTER 5

MIMOSA: A VISUAL ANALYTICAL TOOL

We designed the controlled study to collect a significant amount of data via surveys, interviews, and coded video analysis. In all, we had six teams participate in each of the three display conditions: single, dual side-by-side, and opposing dual shared displays. We opted to code the videotapes at one-second intervals in order to capture ephemeral usage of technology, a frequent occurrence in the field studies. As a result of using one-second intervals, very large datasets emerged, the largest containing 3599 points of time for 15 data sources (resulting in 61,183 data points) and the smallest dataset contained 487 points of time for 17 data source (resulting in 8279 data points). For each team, we captured the following information for every second of the collaboration process:

- Slides displayed on shared display 1
- Slides displayed on shared display 2
- When a key fact was first verbally mentioned
- When an insight was first verbally mentioned
- Who was speaking
- Who was pointing/gesturing towards a shared display
- Who was standing at the whiteboard writing

With the large numbers of elements within each data set, it quickly became apparently we would need to develop a method to visualize the activities occurring during the experiment session. We specifically sought to develop a way to better explore the relationships between the low-level activities occurring during collaboration.

The datasets we created are essentially time-series data, where event X_i occurs at time T_i, where event X_i may be associated with individual P_j. Existing visualization methods, such as simply plotting events along an axis of time, can provide answers to basic time-series data tasks such as determining if a particular individual is speaking at a specific time index. However, with such a large number of time points, this method of visualization can quickly become difficult to render without occluding data points. Conversely, by changing the scale to zoom in on a particular area of the plot, a user loses the overall context of the data set. Thus, we realized we needed to create a system using the information visualization technique of "overview+detail" (Shneiderman 1996) to visually represent our logged data. Overview+detail allows a user examine specific details while still maintaining context to the rest of the data set via an overview plot.

While observing the meeting process, we noted the well-documented phenomena of different groups of individuals meeting having different styles of collaboration (Poole, Seibold et al. 1985). Meetings are more than simply the dissemination of information, but include subtle and direct interaction amongst individuals, data, and technology. Therefore, we saw not only a need to design a way to visualize the logged data sets to support typical tasks an end-user would perform on time-series data (i.e. Muller), but also allow the user to gain additional details of the events occurring, such as seeing the exact content being displayed on a shared display or who was gesturing at the display.

We also recognize a need to expand past simply creating a visual representation of the logged data, but also support a user in understanding and finding out more about phenomena he or she may observe. For example, a user could visually spot a correlation between activities X and Y at time T. We wished to support the user in further investigating this correlation; was it a one-time occurrence or an instance of a pattern? While visualizations allow a user to manually spot these correlations by leveraging the abilities of the human perceptual system, we recognize offering data analysis tools could offer advantages in automatically finding trends or learning more information about a phenomena.

At a high level, we recognized a need for *visual analytics* (Thomas and Cook 2005) to support discovering relationships and correlations between data. Visual analytics is an emerging research field combining information visualization with data analysis techniques. We developed a new visual analytic system, Mimosa, to support end-user sensemaking of the data from the controlled studies.

5.1 Mimosa System

Mimosa is a visual analytic tool built using Flex (Adobe 2009), an application framework for Macromedia Flash Player, and Flare, a visualization library (Heer 2009). We opted to use this application platform and framework to support multiple operating system platforms. Also, Flex, Action Script, and Flare facilitated us rapidly building prototypes and iteratively refining Mimosa. Our goal in designing Mimosa was to remain user-centric and we constantly revisited (and added to) the set of tasks an analyst would perform when investigating the datasets. In particular, we support traditional tasks a user would typically ask of time series data, such as:

- At what time index does an element occur?
- How often does a data element occur?

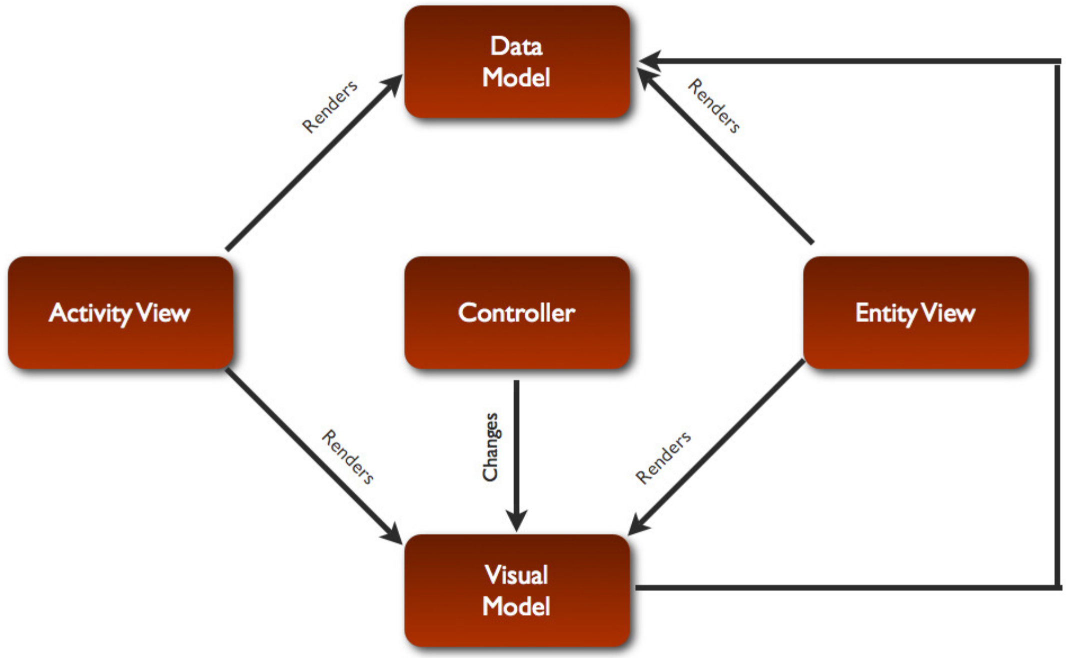


Figure 20: Mimosa system architecture uses the Information Visualization Reference Model (Chi 1999).

- How long does a data element occur?
- What data elements occur together?

We support these tasks through visual representation of the data and through a query tool. Mimosa's query tool allows users to ask questions of the data set and receive statistics matching their query. We discuss the Mimosa system in the subsequent part of this chapter.

5.1.1 System Architecture

We built Mimosa using principles of the Information Visualization Reference Model (Chi 1999), shown in Figure 20. Specifically, this model facilitates having multiple views of the same meeting model. Through user manipulation of controls and queries via the user interface, Mimosa's controller responds to changes, such as a shift in focus, and updates the visual and data models, synchronizing the representation of the data. As an example, if a user moves the focus to a three-minute period within the overview portion of the visualization, all corresponding and related views (including the detail portion of the visualization, content being displayed on the shared display, etc.) are updated simultaneously and smoothly. Using the system architecture of the Information Visualization Reference Model allowed us to design Mimosa to provide a fluid experience in changing visualization scales.

5.1.2 Data Model

Mimosa parses time-series data provided via a comma-separated value (CSV) file where each row represents a particular time interval (in the case of this data set, one-second intervals). Each column represents a particular event or activity. Thus, an element at each row and location represents the occurrence of a particular phenomenon at a moment in time. We opted to use this logged/polled data format to support future studies that can capture data automatically via cameras and microphones.

Mimosa applies user-defined rules to convert the logged data into an XML format for the visualization component of the process. Appendix C includes a sample of the XML format we use to represent data. Specifically, we convert information from log CSV file format into meeting-specific phenomena:

1) **Entities**: Including meeting attendees, locations, and artifacts such as slides
2) **Entity Relationships**: Including content "owned" by a specific individual, such as associating Participant 1 with a slide P_1S_1
3) **Activities**: Actions and events that occur (e.g. a meeting attendees speaking, gesturing, writing on the board)

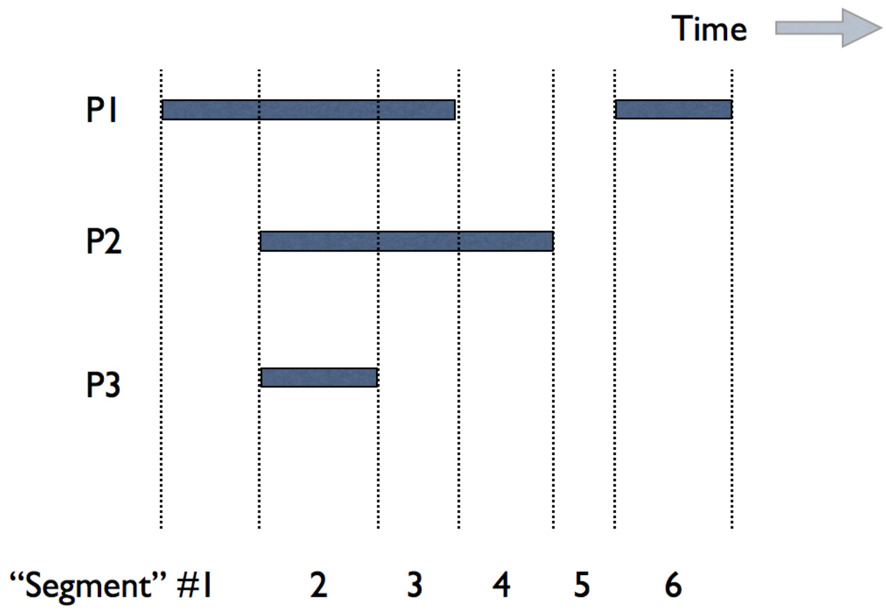


Figure 21: Defining segments of the occurrence of events as used in the Mimosa system.

4) **Activity Relationships**: Including how an entity is involved in an activity (e.g. a meeting attendee shows a slide, slides appear on displays)

Using this schema, Mimosa maps data into a series of *occurrences*, where each occurrence represents the existence of a particular activity at a point in time involving a set of entities. Occurrences can be instantaneous and ephemeral, or last for a duration of time. For example, some occurrences may be as short as a second when someone points to a display.

To accommodate for the variation in times of occurrences, Mimosa sorts occurrences of events and/or activities chronologically upon initialization, ordered by their respective starting times. Mimosa then creates a series of *segments*, consisting of time ranges in which unique combinations of events and/or activities occur. We define segments by the start and end times of an event or activity.

Figure 21 illustrates an example of how Mimosa organizes the logged data into a series of occurrences and segments. In this figure, three participants (P1, P2, and P3) perform some sort of activity (i.e. speaking). Depending on the time index, speaking is performed in parallel amongst multiple participants, independently, or not-at all. In Figure 21, six distinct segments are defined. Segment 1 only has Participant 1 speaking, while Segment 2 has Participants 1, 2, and 3 speaking in parallel. Mimosa calculates all segments upon startup in order to optimize query performance by looking only at segments that match specified time intervals. We discuss the query capabilities of Mimosa in greater detail in Section 5.1.4.

5.1.3 Interface Design and Interaction Techniques

We present the main user interface for Mimosa in Figure 22. Mimosa's interface consists of an overview+detail display with controls for manipulating the presentation of

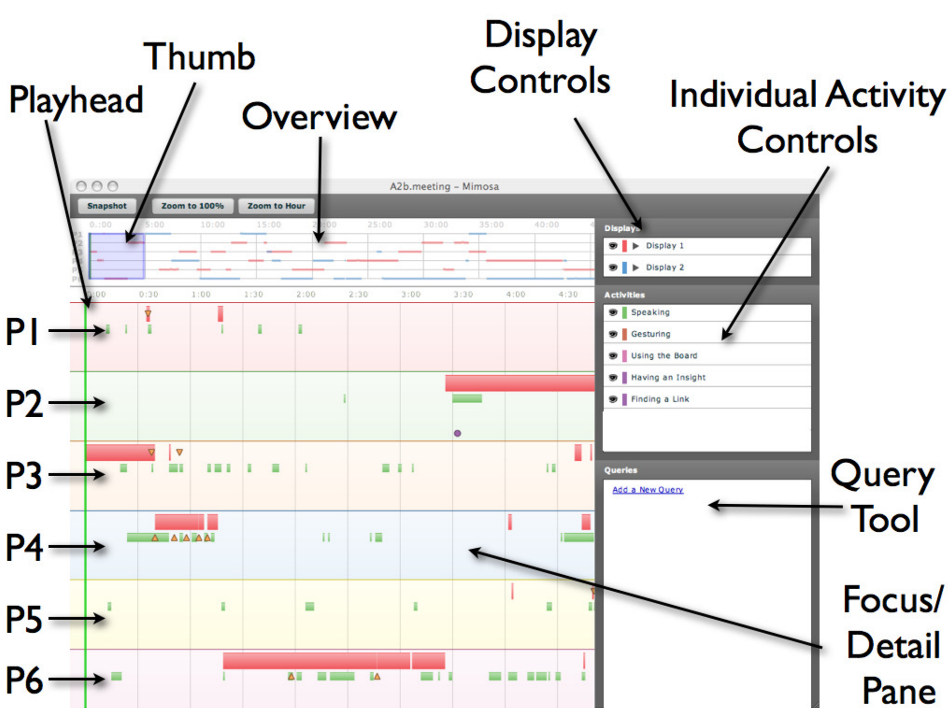


Figure 22: The Mimosa interface is divided into overview + detail panes with individual controls for activities.

various events occurring in the data set. Mimosa also provides a query tool to support a user exploring relationships in the dataset.

The overview pane shows control of the shared display(s) over the entire duration of a meeting. Pink lines denote a participant using Shared Display 1 and blue lines denote a participant using Shared Display 2. Mimosa plots display usage for each participant, arranged top-to-bottom (Participant 1 is the top row in the focus and overview panes, while Participant 6 is plotted in the bottom row.) The overview and detail panes follow Western cultural norms in using spatial dimensions to represent linear time: time starts from the leftmost axis and progresses towards the right side.

The blue dynamic *thumb hover* shown in the overview pane of Figure 22 controls the amount of time represented in the focus/detail pane. By using the scroll wheel on a mouse or multi-touch gesture scrolling on touch pads, an end-user is able to rapidly enlarge or decrease the size of the thumb hover on the overview pane. The thumb may also be repositioned by clicking and dragging either on the overview or investigative pane, allowing a user to quickly examine a new part of the dataset. When a user manipulates the size and location of the thumb hover, the focus pane of the Mimosa interface immediately updates and automatically rescales and updates the time interval markers in the detail pane.

Mimosa's focus/detail pane plots additional details about activities occurring during the collaboration using colors and shapes, including:

- Attendees speaking (green bars)
- Attendees using the white board (brown bars)
- Attendees gesturing to a shared display (light purple)

- Key fact being made (purple circle)
- Insight being made (purple square)

The six participants' data series are laid out similarly to display usage by using natural mapping; Participant 1's activities are the top row of both the investigative and detail panes, followed by Participant 2's, etc. If a particular event such as speaking, gesturing, or writing at the board occurs, a mark is made at that instant of time. We used color and shapes as visual encodings of events, similar in approach to the LifeLines visualization of personal histories (Plaisant, Milash et al. 1996). A user may customize the color in which any activity is plotted via the technology controls in the upper right-hand quadrant of Mimosa's interface.

5.1.4 Mimosa Attributes

Mimosa offers several advantages over using traditional graphing software applications, such as Microsoft Excel or Spotfire. Specifically, we support the investigative sensemaking process by offering several layers of user-enabled focus on the data set through the thumb hover, as discussed earlier, and also a *playhead.*

Using a metaphor from a video cassette recorder (VCR), we a *playhead* can be positioned at a particular instant in time by using click-and-dragging principles. This playhead allows the end-user not only see who had control of a display, but what content was being displayed on the shared display(s). Clicking on the drop-down arrow next to either display in the technology activity pane of the Mimosa UI shows the slide being shown.

During the iterative design process for Mimosa, we found it valuable to allow a user to change the color and intensity of the markings in the focus pane, as well as turning off the rendering of a particular data series. For example, if a user wants to examine speaking patterns, he or she can either turn off other data series that may occlude the speaking data series. We also allow a user to increase the intensity of the rendering of speaking patterns amongst the other data series.

Query Capabilities

We also designed Mimosa to allow a user to conduct queries on the dataset to support investigative analysis (Figure 23). Again, we wished to facilitate a user exploring relationships within these datasets. Our query interface empowers an end-user to ask questions regarding the datasets, see matches to queries highlighted within the data set, and also provide basic statistics.

For example, imagine a user is exploring a data set and focuses on a subset of the timeline. He or she notices a relationship between two data elements, D_1 and D_2 occurring at point T_x. By providing the user with the ability to run queries, he or she can instruct Mimosa to identify any other occurrences when D_1 and D_2 occur at the same time. Mimosa highlights time intervals in the detail pane that match the query and also

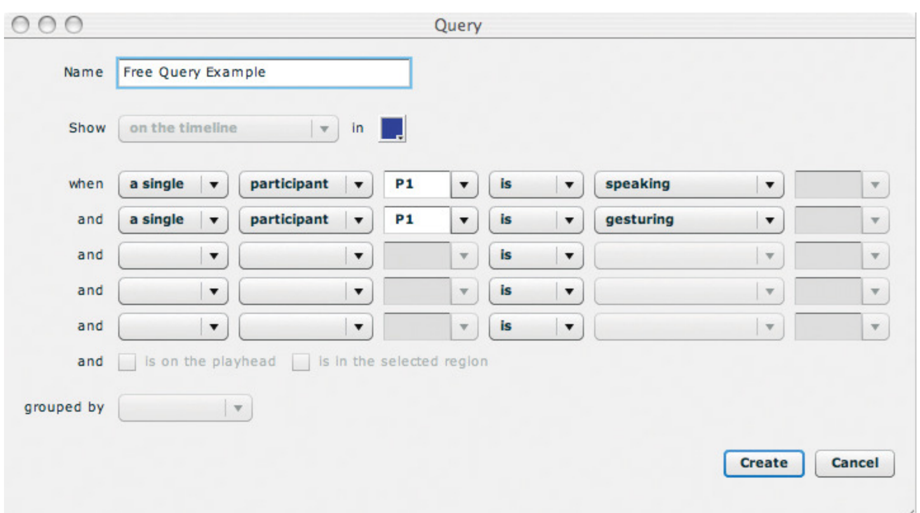


Figure 23: Mimosa's query interface dialog.

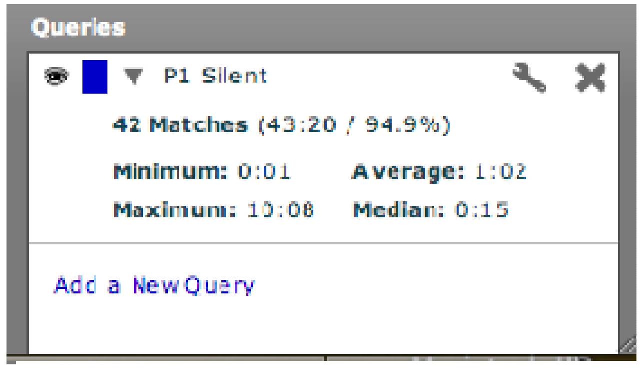


Figure 24: Query result for, "*Show me any instance when Participant P1 is not speaking*."

presents the user with descriptive statistics (i.e. Figure 24) including:

- Total duration of the time matching the query
- Percentage of time matching the query
- Statistics for the minimum, maximum, mean, and median duration of the matches to the query

In Figure 23, a query is issued to show all instances when Participant P1 was not speaking. Figure 24 illustrates the query results, showing that Participant P1 was silent for approximately 94.9% of the entire meeting. By providing this additional information, Mimosa facilitates the sensemaking process of an end-user. For example, the end user can now explore other situations, such as determining if Participant 1 speaks less than the least talkative group member of other meetings, or if Participant 1 is generally the least-talkative person in all groups. Thus, the user is able to gain more information and context to actively redefine his or her conceptual understanding of the data.

During the iterative design process for Mimosa, we consistently reflected upon typical questions an analyst would ask when exploring the datasets, and used these questions in developing Mimosa's query language. Examples of tasks include:

- In dual display conditions, do participants prefer using one display over the other?

- Which participant talked the most?
- Which participant talked the least?
- Did the participant who talked the most also gesture the most?
- Did any other activity correlate to discovering a key fact or insight?

Mimosa's query language is based on fulfilling constraint satisfaction. The analyst specifies a set of entities and activities and the relationships between them using the graphical interface shown in Figure 23 and Figure 25. We opted to use a graphical interface using drop-down menus to ensure visibility of all the possible query operations. We do acknowledge using a command-line based syntax would improve the speed at which a user can implement a query, however, that approach requires the user to learn the language syntax. For the current generation of Mimosa, we focused on supporting the user in exploring the data sets and not have to recall the syntax of the query language.

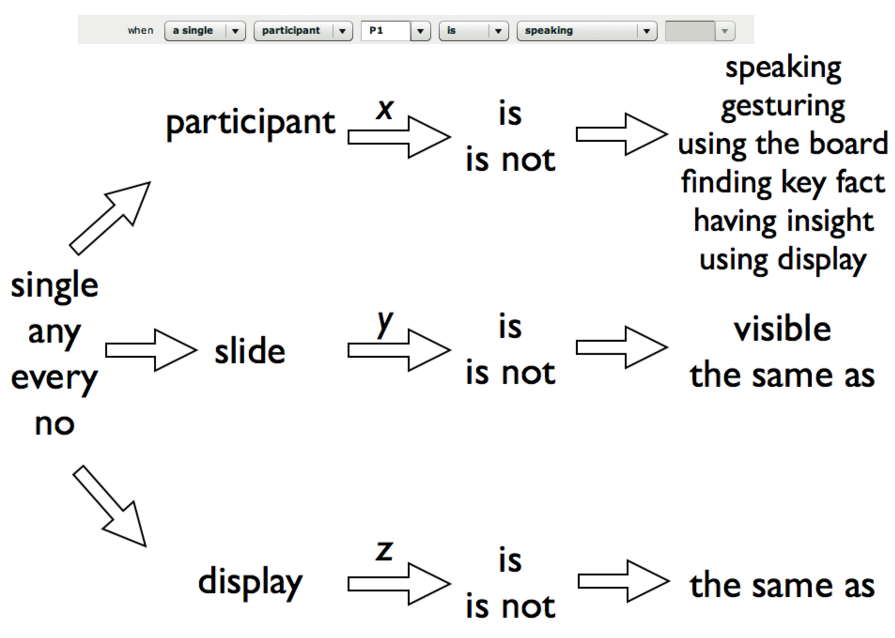


Figure 25: An example of Mimosa's query language structure.

Currently, Mimosa supports two types of constraints:

- **Bound**, where specific activities or occurrences are designated. An example of such a query is, "*Show me when Participant 1 is speaking*."

- **Free**, where relationships between multiple entities and activities and creating compound queries. An example of such a query is, "*Show me when Participant 1 is both speaking and gesturing towards a shared display*."

5.2 Related Temporal Categorical Visualization Systems

Many research and commercial systems visualize data events or phenomena containing a temporal component. In this section, we characterize key features of Mimosa with respect to other visualization systems. Specifically, we compare Mimosa to systems visualizing events occurring in linear time (where events are not occurring in a cyclic fashion). Linear temporal categorical data is generally plotted as events occurring along an axis representing time, but systems vary in the visual encodings they use as well as the computational analysis support, if any, they provide.

KNAVE-II visualizes large volumes of time-oriented security data such as computer virus or worm attacks using a linear representation and supports overview+detail via zooming (Shabtai, Klimov et al. 2006). Mimosa similarly supports focusing on a specific area of the timeline while maintaining context with the larger dataset, but Mimosa also uses a gesture-controlled thumb hover to dynamically change the amount of information in focus. Both KNAVE-II and Mimosa provide the end-user with basic descriptive statistics regarding the dataset such as mean, maximum values, and standard deviations, but Mimosa allows the end user to form compound queries on the dataset, returning localized statistics and highlighting query matches on the visualization.

Session Viewer is a visual analytic system showing multiple coordinated views to support examination of time-stamped user actions, referred to as session logs (Lam, Russell et al. 2008). Session Viewer displays multiple datasets using vertical views to facilitate the comparison of different groups. Currently, Mimosa only visualizes one meeting at a time; however, the modular system architecture facilitates visualizing multiple meetings simultaneously and is planned for a future system extension (see Chapter 7).

Other similarities between Session Viewer and Mimosa include the use of coordinated views, where updates in one view of the data result in simultaneous updating of another view, and both systems calculate basic statistics. However, Session Viewer and Mimosa target different audiences; Session Viewer supports seasoned analysts who are trained to observe specific phenomena within logs. Conversely, Mimosa is designed to support general users without any specific training and to facilitate iterative and interactive exploration of logged meeting datasets. As a result, Mimosa uses a dialog box to reveal the structure of the query language syntax while Session Viewer uses a scripting language to perform queries, requiring memorization and recall of query syntax.

Mimosa also shares some similarities with LifeLines2, a system that visualizes records over time (Wang, Plaisant et al. 2008). LifeLines2, like Mimosa, aims to support user recognition of hidden patterns within the data and supports users building abstractions of data sets. Records are vertically stacked on a timeline and color is used to distinguish each record; triangle icons represent events. Both Mimosa and LifeLines2 contain controls to support filtering the visualization, but LifeLines2 also offers the ability for a user to rank data. LifeLines2 and Mimosa differ in their support of query formulation; LifeLines2 uses direct manipulation where the end user aligns, ranks, and filters data to form queries. Mimosa supports a user in visually recognizing patterns and correlations within the datasets, but also provides computational support via a formal query interface, allowing a user to quickly discover (and quantify) relationships within other areas of the dataset

Two widely-used commercial software packages also provide similar features to Mimosa. The Morae and Noldus Observer XT (Noldus 2009; Smith 2009) software suites support management and basic visualization of data acquired from user research. Morae supports data collection through recording activity occurring on a participant's screen or logging window events or mouse clicks. Morae also supports a user marking events occurring in real time or during post-experiment video analysis, and then places these markers as color-coded diamonds on a timeline as a simple visual representation of the observed phenomena.

We did not design Mimosa to facilitate data collection. Rather, Mimosa is designed to support a user making sense of the logged temporal categorical events occurring during meetings. Mimosa offers several advantages to the visualizations used in Morae. In particular, we support overview+detail in our visualization, allowing a user to examine a subset of time in more detail while maintaining context with the larger data set. In addition, Mimosa supports compound query formulation and filtering, allowing a user to explore relationships within the data.

Noldus Observer XT also supports data management via a user coding events in real-time or posthoc via video analysis. Noldus also allows a user to define event schemes to convert raw behavioral events into more meaningful information. Similarly, Mimosa uses an XML scheme to translate data from logged actions into more information units, such as entities (i.e. participants, locations), relationships (a participant "owning" a slide), and activities (i.e. a participant writing on the board). Again, Mimosa's contribution is not obtaining or facilitating data collection, but translating data into meaningful information and supporting iterative end-user investigation of the dataset via queries. In regards to visualizing data, Noldus uses a similar paradigm as Mimosa in using color and shapes to plot the occurrence of activities on a timeline. However, Noldus does not include an overview of all activities to provide additional context to a user.

5.3 Mimosa Conclusions: Supporting Sensemaking

Mimosa creates visual representations of events and activities occurring while teams collaborate on a sensemaking task. That is, teams are sifting through large amounts of data, facts, and charts, and are constantly updating their understanding of a non-trivial situation. The intent of acquiring this information was to ascertain whether the presence and location of multiple shared displays impacted how teams performed this sensemaking task.

As a visual analytic tool, Mimosa supports end-user sensemaking of these data sets, going beyond analyzing data using summary, descriptive, and inferential statistics. By enhancing the visual representation of data with analytical capabilities, Mimosa supports users discovering trends or relationships within the data sets and exploring these relationships in additional detail.

In Chapter 6, we discuss the results of the controlled study and how Mimosa was used to uncover relationships in the datasets.

CHAPTER 6

CONTROLLED STUDY RESULTS

In the laboratory study described in Chapter 4, we collected qualitative and quantitative data in the form of questionnaires, interviews, measuring time for each group to reach consensus, and logging events via coding videotapes of each experiment session. In particular, we logged the following information:

- Slides appearing on shared display 1 and shared display 2
- When a key fact was first verbally mentioned
- When an insight was first verbally mentioned
- Who was speaking
- Who was pointing/gesturing towards a shared display
- Who was standing at the whiteboard writing

We employed several evaluation techniques to analyze the qualitative and quantitative data obtained from the controlled study. We used descriptive and inferential statistics as appropriate to determine general trends within the quantitative data. We also used inductive coding to establish emerging themes from observations and interview data. Finally, we also used the Mimosa visual analytical tool described in Chapter 5 to explore the relationship between the various activities occurring while groups collaborated.

Table 9: Performance metrics per display condition.

Opposing Dual Display Condition

	1	**2**	**3**	**4**	**5**	**6**	**Condition Average**
Time to reach consensus (in min)	22.4	47.2	46.5	21.5	23.8	29.0	31.73
Number Key Facts Identified	9	10	9	8	6	10	8.7
% Key Facts Identified	75%	83.3%	75%	66.7%	50%	83.3%	72.5%
Number Insights Found	1	0	1	1	2	1	1.0
% Insights Found	20%	0%	20%	20%	60%	20%	20%

Side-by-Side Dual Display Condition

	1	**2**	**3**	**4**	**5**	**6**	**Condition Average**
Time to reach consensus (in min)	45.7	23.0	8.1	29.3	33.3	24.0	27.24
Number Key Facts Identified	11	9	6	8	7	8	8.2
% Key Facts Identified	91.7%	75%	50%	66.7%	58.3%	66.7%	68.1%
Number Insights Found	5	3	1	3	1	4	2.83
% Insights Found	100%	60%	20%	60%	20%	80%	56.7%

Single Display Condition

	1	**2**	**3**	**4**	**5**	**6**	**Condition Average**
Time to reach consensus (in min)	35.4	26.6	40.1	60.0	33.1	29.2	37.38
Number Key Facts Identified	4	9	10	10	5	10	8.0
% Key Facts Identified	33.3%	75%	83.3%	83.3%	41.7%	83.3%	66.7%
Number Insights Found	0	3	1	0	3	3	1.67
% Insights Found	0%	60%	20%	0%	60%	60%	33.3%

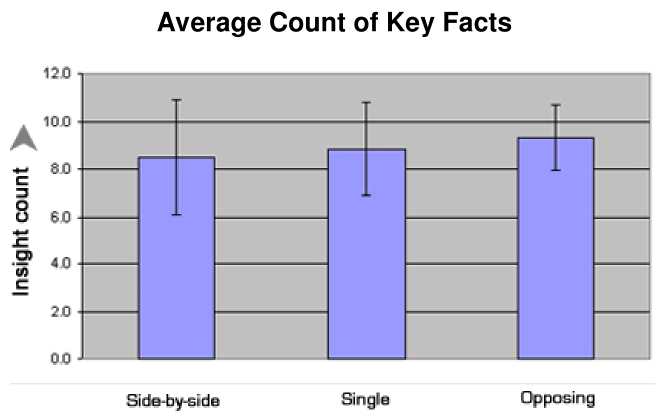


Figure 26: Average count of key facts discovered per display condition. The arrow represents the direction of better performance.

Figure 27: Average number of insights made per display condition. The arrow represents the direction of increased performance. Stars indicate a significant difference between groups.

We sought to evaluate how groups completed the sensemaking tasks in the various display conditions using the metrics of *performance*, *collaboration*, and *satisfaction,* as described in the following sections.

6.1 Performance Results

To explore the effect of display condition on performance, we examined the rate of key fact discoveries and insights made by each group in each of the three display conditions: single, side-by-side dual, or opposing dual shared displays, as illustrated in Table 9. We also measured the time it took each team to reach consensus regarding the collaborative task. Since the number of groups per condition is limited, we use a general

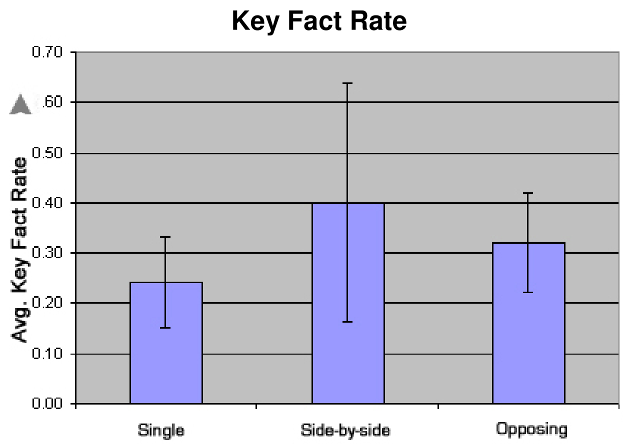


Figure 28: Key fact rate per display condition. Each group's key fact count is divided by their time-to-completion. The arrow represents the direction of greater performance.

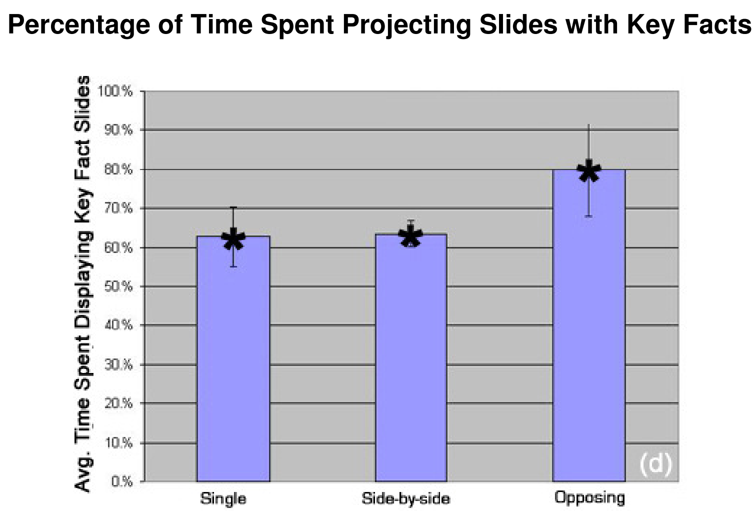


Figure 29: Average time spent displaying slides containing key facts, per display condition. Stars indicate statistical significance.

comparison of trends as an analysis. However, we offer inferential statistical analysis when appropriate to also provide useful indicators of trends. Figure 26 and Figure 27 graphically show the average count of key facts observed and insights made for each display condition.

However, the time for each group to reach consensus varied considerably per group, with a mean time to completion of 33 minutes across all groups. For example, one group in the side-by-side display condition reached consensus in 8:07 while another took

45:39. This wide variation is perhaps the greatest challenge in evaluating performance amongst groups collaborating; the way individuals interact with each other as well as establish a rapport may vary considerably and is well-documented in existing literature (e.g. (O'Connor 1980)).

To account for this variation in time-to-completion, we calculated a rate for groups finding key facts by dividing the number of key facts discovered by the amount of time it took to reach consensus to obtain a rate. As Figure 28 illustrates, the average key fact observance rate is highest for groups in the side-by-side display condition compared to the opposing dual-display and single shared display conditions. However, the side-by-side dual display condition also has the largest variance. The rate of finding key facts is lowest for individuals in the single shared display condition. While these differences are not statistically significant, they indicate the possibility of different collaborative behaviors occurring in each display condition and merits further analysis.

There was a significant effect ($F(2,17)=4.448$, $p=.030$) on display condition on the number of insights discovered, as shown in Figure 27. A post hoc analysis indicates that participants in the side-by-side condition made significantly more insights than those in the opposing display condition. Although the average number of insights (1.67 vs 2.83) was lower under the single display versus the side-by-side condition, this difference was not quite statistically significant at the $\alpha = .05$ level.

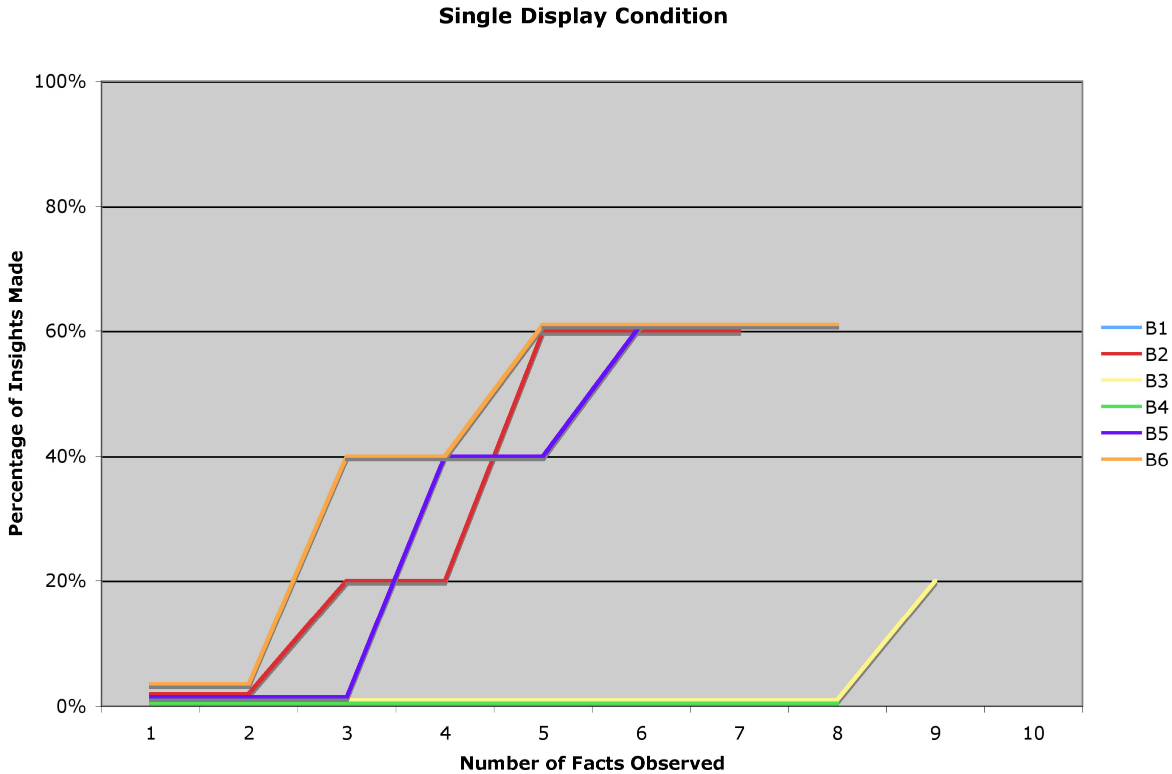


Figure 30: Plot of percentage of insights made as a function of the number of facts discovered for the single shared display groups.

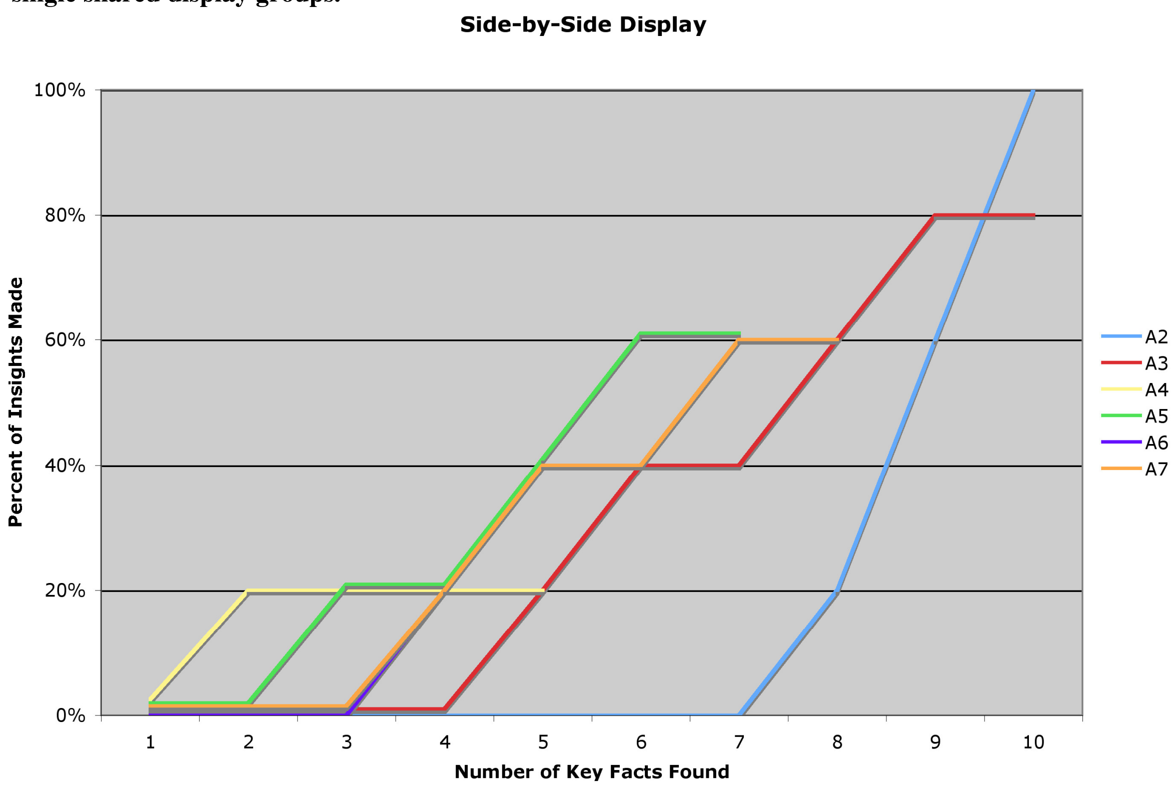


Figure 31: Plot of percentage of insights made as a function of the number of facts discovered for the side-by-side dual display condition.

We also analyzed the amount of time groups spent displaying slides on the shared displays. An ANOVA analysis yielded a significant difference in this factor (F(2,17)=8.099, p=.004). Groups in the opposing dual display condition spent a significantly larger percentage of their time showing slides containing key facts on a shared display than those in the single display condition or side-by-side display condition, as shown Figure 29.

To further explore the differences indicated by Figure 27 and Figure 28, we analyzed transcripts of each testing session and time-stamped comments. We used this information to plot the percentage of insights made by each group as a function of the number of facts discovered, as illustrated in Figure 30, Figure 31, and Figure 32. We also include larger versions of these plots in Appendix D. We note that while an ANOVA analysis did not yield a statistical significance between single and dual side-by-side

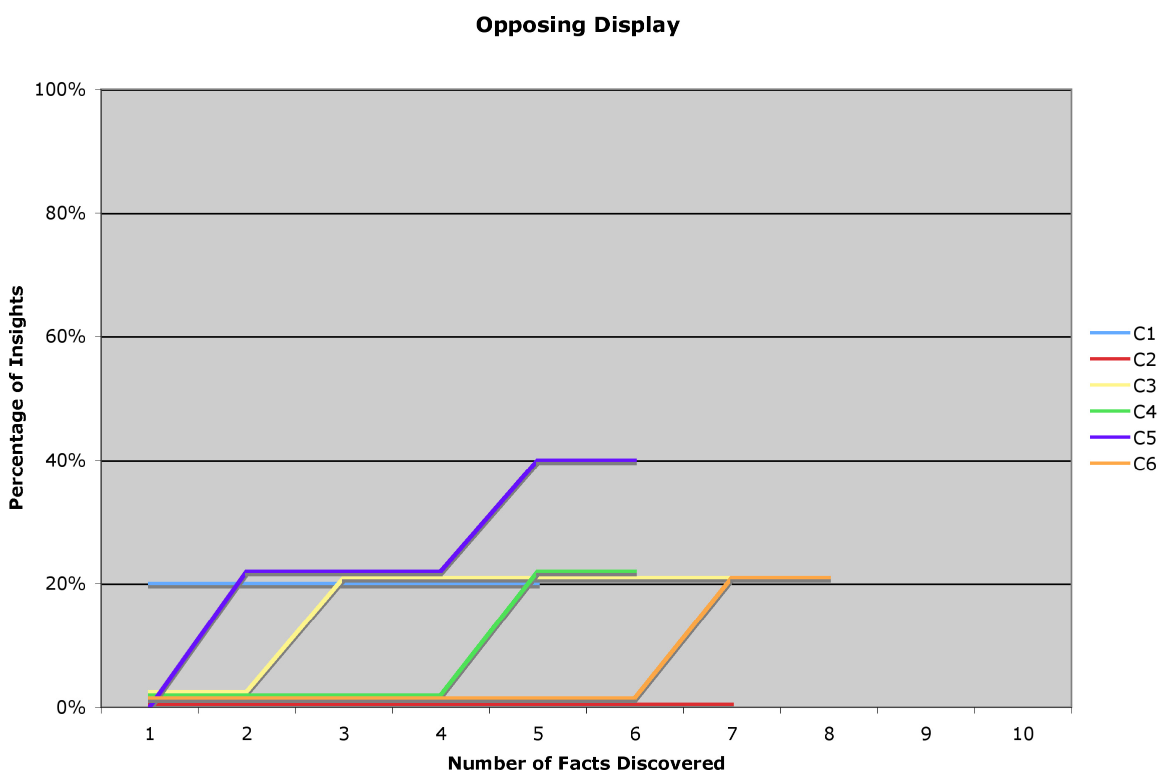


Figure 32: Plot of percentage of insights made as a function of the number of facts discovered for the the opposing dual display conditions.

shared display conditions in terms of the number of key facts observed or insights made, the plots shown in Figure 30 and Figure 31 indicate quite different patterns of observing facts and making insights.

We identified several trends from the plots shown in Figure 30, Figure 31, and Figure 32. Across all three display conditions, there is a positive correlation between the number of insights made and the number of facts observed, with the exception of groups that did not make any insights (single display condition groups B1 and B4, and opposing display condition group C2). The relationship between facts discovered and the percentages of insights made is not linear (with the exception of groups not making a single insight as well as group C1), but more resembles a logarithmic function.

Second, we note that as a group discovers more facts, we see an increased likelihood of insights being made. However, after reaching a saturation point, observing

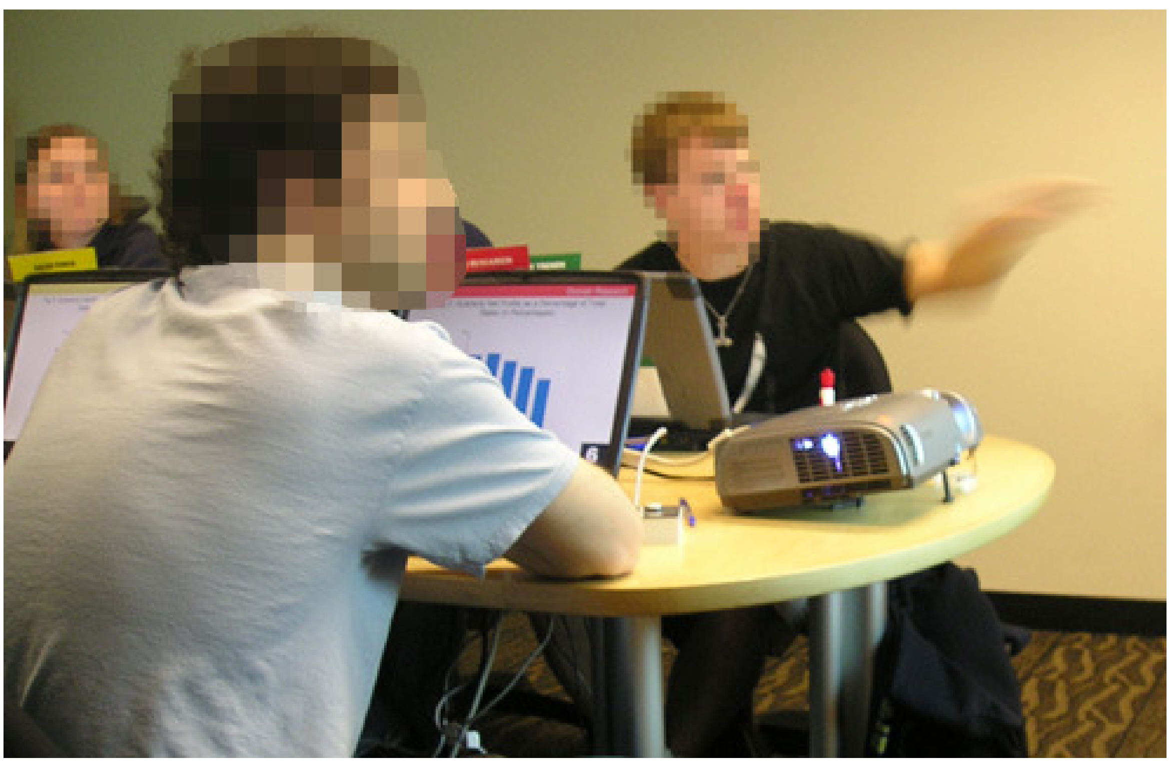


Figure 33: Deictic gesture used by a team member to call attention to the shared display.

more facts does not necessarily lead to a group having additional insight, a trend exhibited in 62.5% of all groups (A4, A7, A3, C1, C3, C4, C5, C6, B2, B6). Furthermore, the only group that discovered all the insights, as defined by our experts, was side-by-side display condition group A2.

6.2 Collaboration

To evaluate collaboration, we coded the videotape of each session for gesturing and whiteboard usage, each an act that involves interaction with other individuals. Prior research indicates that individuals use pointing gestures during collaboration to clarify or enhance a message (Fussell, Setlock et al. 2004), as shown in Figure 33; furthermore pointing gestures can facilitate performance during collaborative tasks (Cassell 1998). We counted each instance of deictic gesture towards the display via video analysis. Likewise, we also noted when a group member stood and actively wrote on the board.

6.2.1 Quantitative Measures

Figure 34: Single-display condition group using the whiteboard to record trends in data.

Table 10: Count of groups where whiteboard was used.

Condition	Count	Total Duration at Whiteboard (Average Time Per Encounter)	Usage
Single	4	01:32(*00:46*)	Observation of Facts
		38:45(*12:55*),	Observations / Synthesis
		06:48(*01:21*)	Observations of Facts
		05:11 (*01:43*)	Observations of Facts
Side-by-Side	1	06:07 (*00:33*)	Observations of Facts
Opposing	2	01:57(*00:58*)	Observations of Facts
		04:11(*04:11*)	Observations of Facts

Groups in the single shared display condition used the whiteboard more frequently than in any other condition (Table 10). Whiteboard usage served primarily as a way to make note of observations or insights. In these cases, participants used whiteboards as persistent information displays where group members wrote down key observations from the data set as the group proceeded to analyze the scenario and case files. The group (single display condition group B4) that used the whiteboard for the longest amount of time in the single display condition also recorded observations, but also synthesized trends in the data, and even combining trends to form new graphs (Figure 34). We note that three of the four single display groups using the whiteboard (B3, B4, and B6) each observed 10 out of the 12 key facts. The remaining single display group that used the whiteboard (B5) only observed 5 key facts while the two groups who did not use the whiteboard (B1 and B2) observed only 4 and 9 key facts. Thus, the groups that recorded the highest number of key facts in the single display condition utilized the whiteboard during their collaboration.

Proximity to the whiteboard correlated to which group member would write down the observations on the whiteboard. In all groups using the whiteboard but one (single display group B4), the group member seated closest to the whiteboard was the individual

Figure 35: Mimosa visualization of meeting with the most whiteboard usage. Note Participant 3 assumed leadership and has a corresponding high speaking level (green ticks) Furthermore, since he was at the whiteboard, his slides were not displayed often (pink intervals).

who wrote on the board. In single display group B4, the individual who went to the whiteboard was seated on the opposite side of the table.

To explore this more, we used Mimosa (described in Chapter 5) to visualize the meeting process for group B4 and present the image in Figure 35. In this visualization, we can see that during the initial few minutes of the collaboration, no green marks are plotted, thus no one spoke—indicating a period of initial uncertainty common in many meetings. Over the next ten minutes, Participants 1, 3, 5, and 6 all briefly share content on the shared display, three key facts are observed, but the group does not gain substantial momentum forward in the sensemaking process. At about 11 minutes into the sensemaking activity, Participant 3 assumes a leadership role and relocates himself to the whiteboard, and leads the group from the whiteboard, heavily dominating the conversation for the rest of the meeting, as evident by the high density of green marks.

We also observed deictic (i.e. pointed) gesturing towards the shared display(s) across all experiment conditions. To account for the wide range of completion times, we calculated a gesture rate. An ANOVA analysis yielded statistical significance for gesture rate across the conditions ($F(2,17)=6.364$, $p=.010$) where groups in both multiple display configurations had higher gesture rates than those in the single display configuration. However, the average length of a gesture was similar across conditions: 2.8s, 2.2s, and 2.6s for the single, side-by-side, and opposing display conditions, respectively. Again, we do note that the number of groups per condition is limited, however inferential statistical analysis provides a useful indicator of trends.

6.2.2 Qualitative Measures

We probed aspects of collaboration via surveys, interviews, and used inductive techniques to understand commonalities and themes from the video analysis. In conjunction, the independent raters also inspected the transcripts. In particular, themes revolving around how the second shared display impacted collaboration within the meetings emerged.

<u>Secondary Display Impact on Collaboration</u>

Despite the lack of significant differences in performance metrics discussed in the last section, several findings indicate that the presence and location of the secondary display impacted collaboration. Table 11 reports the average Likert rankings per display condition for the post-experiment survey. Participants in the side-by-side dual display condition ranked how their groups collaborated significantly higher than those in the single display condition ($F(2,103)=3.733$, $p=.027$). Furthermore, Figure 30, Figure 31, and Figure 32 also suggest that the patterns of collaboration varied between display

Table 11: Average self-ranking for post-experiment survey questions. The Likert scale ranged from 1 to 7, where 7 corresponds to strongly agreeing or positive. * denotes a significant difference.

	Single Display	Side-by-Side Dual Displays	Opposing Dual Displays
After hearing and/or reading the initial introduction to the problem, was the correct solution immediately obvious to you?	2.8 (1.56)	2.7 (1.74)	2.4 (1.33)
How realistic was the scenario to you? (Do you believe that this could be an example of an actual decision-making situation within an organization?)	5.0 (1.27)*	5.5 (1.18)	5.8 (0.90)*
How well did you feel the group functioned collaboratively?	5.2 (1.02)*	5.8 (0.96)*	5.7 (0.92)
How satisfied were you with the process in which the group developed their solution?	5.2 (1.10)*	5.8 (1.10)*	5.7 (0.77)
How satisfied were you with the number of ideas the group came up with for the decline of profits	5.4 (1.24)	5.8 (0.92)	5.4 (0.99)
Do you feel the group made a "good" decision?	5.9 (0.98)	6.2 (0.84)	6.4 (0.67)
How useful was the display switching device?	6.5 (0.67)	6.2 (0.92)	6.1 (0.88)

conditions. In fact, after reading the transcripts for all of the sessions, one expert evaluator noted: "*There was an understanding of a shared display as a group resource which someone had to command. If a second display was present, it looked like it could be employed in various ways*." We explore these themes within this section.

Use of Shared Displays for Exploration

In this style of collaboration, a group member would typically notice a particular trend on one of the slides on his or her laptop computer and call the groups' attention to this trend by sharing the slide on one of the shared displays. Other group members would then consult their own information and determine if they had charts, data, or information pertaining to the original insight. This content would be displayed on the adjacent display. This particular strategy was explicitly spoken by one participant in the early stages of his groups' analysis:

> "*Let's try to piece together a little bit of what our problem is and then we can put on information from different sources for resolution. To start off, we are looking for a reason why profits have steadily decreased. We can use both displays to show the slides we have.*"

Multiple shared displays, especially in the side-by-side configuration, further supported exploration by facilitating the comparison of information, a fundamental

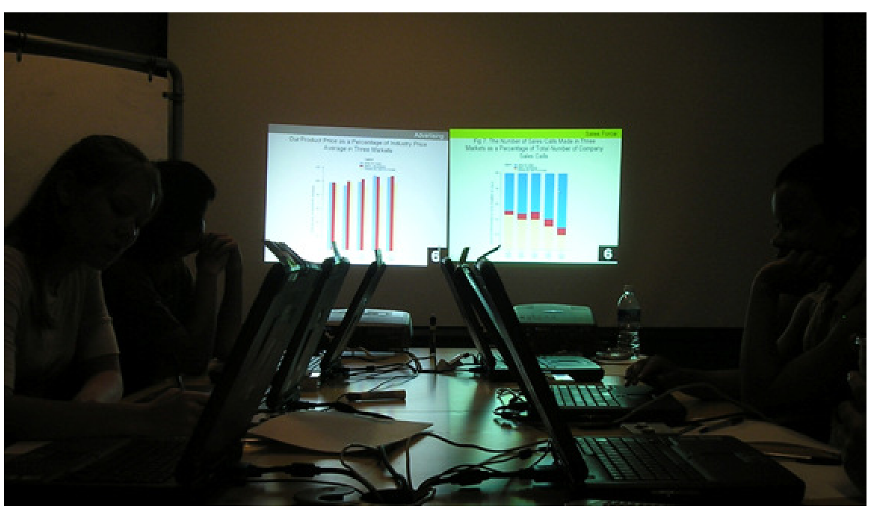


Figure 36: A group using the dual displays to compare two charts side-by-side.

operation performed during sensemaking activities (Thomas and Cook 2005).

Figure 37 shows a Mimosa visualization of an opposing dual display experimentation session. Note when Participant 5 maintains control of one of the shared displays, participants P1, P3, P4, and P5 also display content on the second display. Figure 36 illustrates a side-by-side display condition using both displays to compare charts while performing their sensemaking task.

In addition, we highlight several interesting phenomena illustrated in Figure 37 as team members perform the sensemaking task. Participant P2 does not share much content visually, but actively engages in conversation (green marks). Also, participant P3 does not verbally speak during this interval (absence of green marks), but does collaborate with the other team members by showing slides on the both shared displays (evident by the blue/pink marks). Typically, once the initial uncertainty of the meeting process passes, most participants explored the data set both verbally and by showing slides, as we see with Participants 1, 5, and 6 in Figure 37.

We also note a second style of exploration facilitated by the multiple display configurations. While searching for correlations amongst data, participants would use the second display to actively cycle through another group member's slides, comparing each slide to another participant's on the other shared display (illustrated in Figure 36). The side-by-side display configuration supported direct comparison of two individual's information, thus it is not surprising that this style of exploration occurred almost exclusively in the side-by-side display conditions.

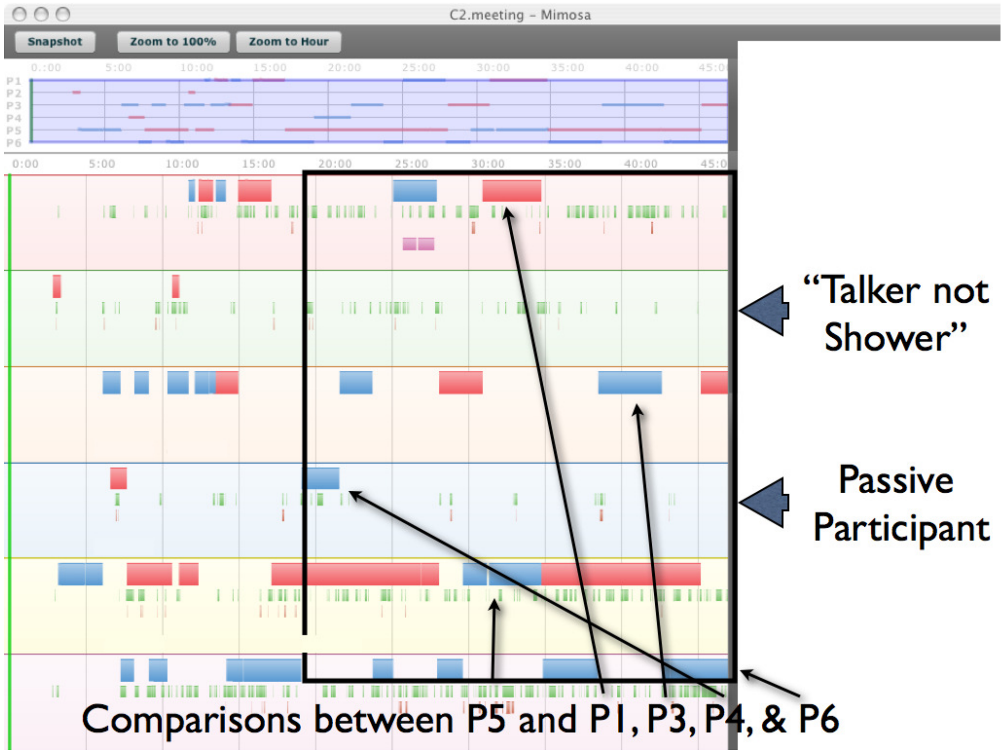


Figure 37: Mimosa visualization illustrating concepts of exploration by comparison and passive participation.

Use of Multiple Displays to Engage

Groups consisted of individuals with very different personalities, some more outgoing than others. All groups had at least one participant who, either due to shyness or a lack of interest, did not frequently join in the verbal discussion. For example, note Participant P3's lack speaking in Figure 37. However, even though this participants did not contribute much verbally, we note that the multiple shared displays facilitated a mechanism to share information visually via the shared display not currently the focus of the groups' analysis, as a way to influence the group's conversation.

Using Mimosa, we further investigated and noted instances of when individuals took "control" of a display by pressing a button on the control box to share content on one of the shared displays. Specifically, we noticed phenomena of *show then tell* and *tell and/or then show* where a team member takes control of a shared display, either from another person who was currently using the display, or else the individual takes control of a blank display. We further defined an instance of *show then tell* as an individual:

1) taking control of a display to share information with other group members

2) begins speaking typically within 10 seconds of taking control. Note, however, that extremely passive participants may not speak, instead allowing more active participants to start a conversation on the information being presented visually.

Conversely, *tell and/or then show* is defined as a group member speaking within 10 seconds prior to taking control of a shared display. Figure 38 illustrates an example of *tell then show* where Participant 4 talks immediately before taking control of Display 2 (blue) from Participant 6. Once Participant 4 finishes talking, Participant 6 comments on the material as well.

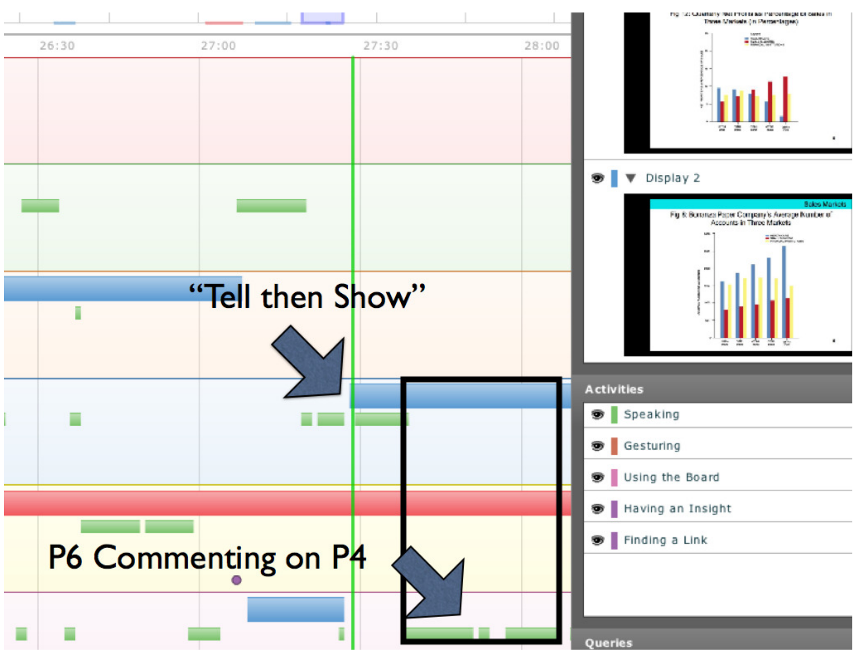


Figure 38: Visualization of dataset that illustrates the "Tell Then Show" interaction. In this dataset, Participant 4 begins to talk before taking control of Display 2 (Blue) from Participant 6.

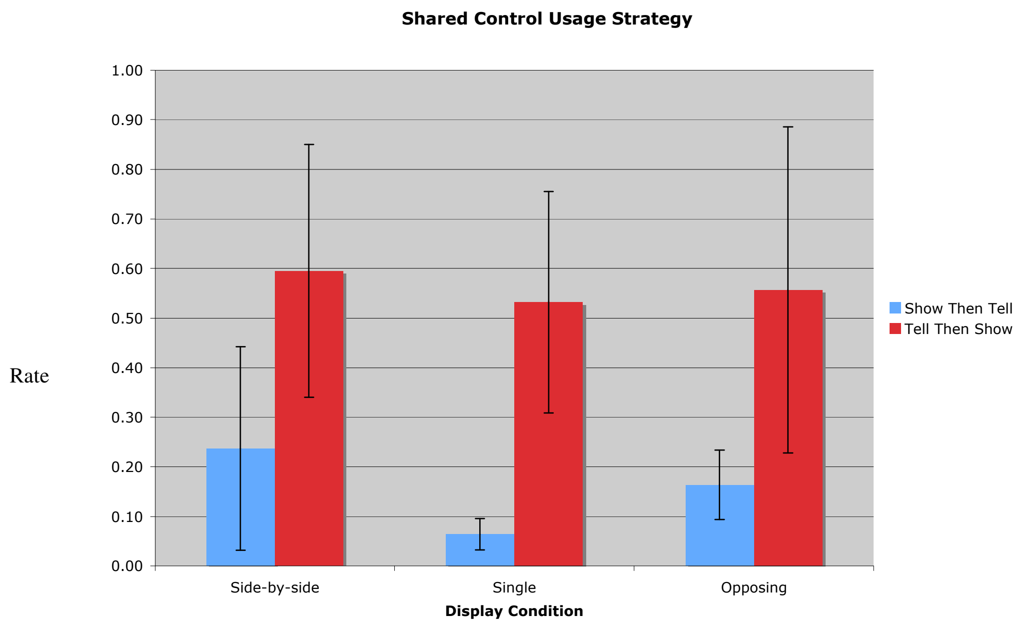


Figure 39: Plots of "show then tell" and "tell and show" phenomena. The data collected was adjusted for varying time-to-completion.

Figure 39 illustrates the *show then tell* and *tell and/or then show* rates for each display condition. Again, due to the variation in times for groups to reach consensus, we normalized each group's count of display control by dividing the time it took the group to reach consensus. The wide range of personalities amongst meeting attendees is reflected in the relatively large standard distributions. Still, these graphs illustrate the general trend that the *show then tell* phenomenon occurs more frequently within the side-by-side dual display condition than with the single shared display, where users are more likely to take a *tell and/or then show* approach to sharing information. Furthermore, we note the maximum rates exhibited by a participant for *show then tell* activity across the three display conditions; 0.53, 0.11, and 0.25 for side-by-side, single, and opposing display configurations, respectively.

A second way that we observed individuals using multiple shared displays to engage more timid team members was by inviting the shy participants to use the nonactive display to share information. For instance, in one group, a participant asks another, "*Is there anything in sales that can help us* [explain this insight]." Another group member asks another, "*You're financial. What do you have regarding healthcare? Put it up on the other projector,"* specifically inviting individuals to use the second display.

Opposing Displays used to Segregate Content

We observed group members using opposing displays to host two different observed key facts. One participant remarked that it was useful to keep different observations separated physically to avoid temptation to draw improper connections between information—that physical proximity of two graphs leads to a temptation to see relationships that may not exist. Figure 40 illustrates an example of this; in this image, the participant in the foreground and an obscured participant have their attention focused on one display, while other group members have their attention towards the other display.

Collaborative style of meetings

Several trends emerged regarding the collaborative style of the meetings under the different display conditions. One of the two domain experts examined the transcripts of the experiment sessions and noted that he felt there was generally high-level discussion occurring within the side-by-side groups with occasional examinations down into more specific details. Note that the rater did not know which transcripts correlated to which display condition. However, the expert's observation of different collaborative processes from the transcripts also supports the trends shown in Figure 30, Figure 31, and Figure 32 that very different patterns of collaboration did occur across the different display conditions.

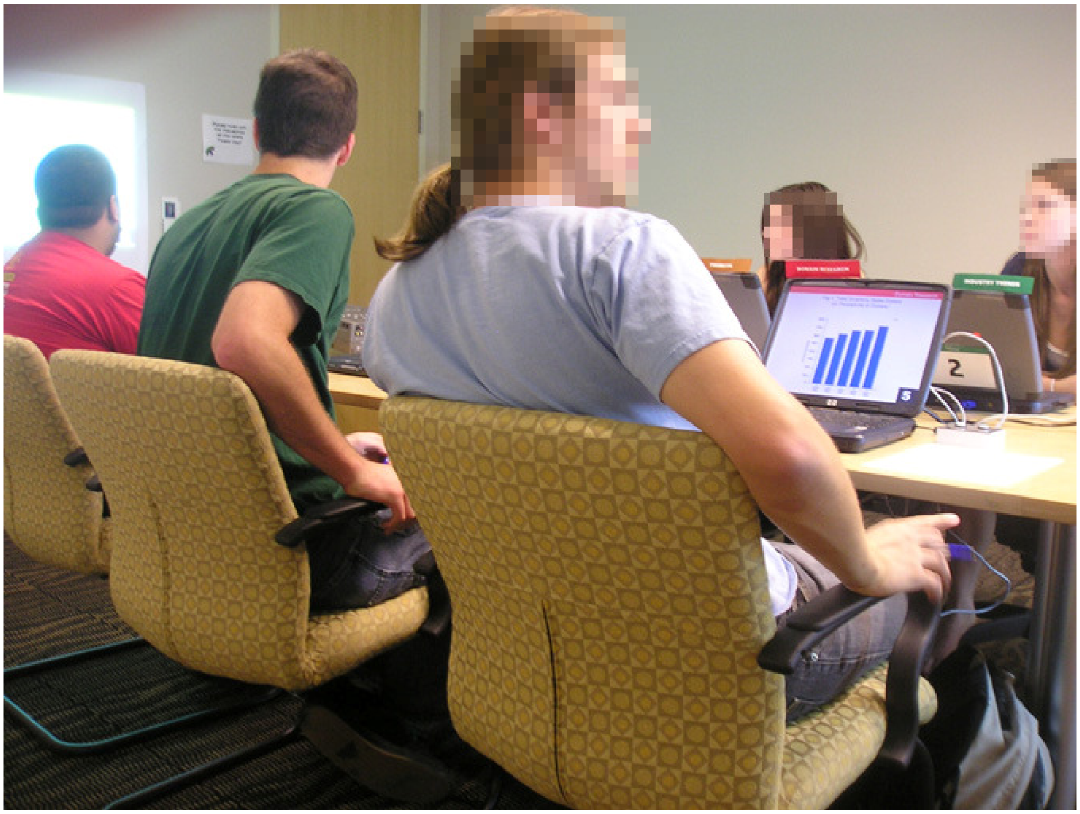


Figure 40: Example of split attention in dual opposing displays condition.

One rater described discussion within single display groups as being "ploddy" where dialog would be abrupt, such as an individual would interrupt a current conversation thread to request to see a different chart. For example, one individual interrupted his own train-of-thought: "*and if you look at sales—can you go back to the same graph?*"

Regarding collaboration, the only instances in which a group actually subdivided into smaller groups occurred in the single display condition (Team B1). During this session, team members on each side of the table worked together and processed information in parallel before collaborating with the other side (Figure 41). In another group, individuals broke down into small groups of similar roles to share information before collaborating with the rest of the group.

Finally, we include Figure 42 to further illustrate common collaborative behaviors occurring across display conditions. In this particular image, we are visualizing the speaking and display control patterns of a single-display condition group B2. The overview plot of the Mimosa visualization clearly shows the initial uncertainty and cautious interaction characteristics of the start of most meetings, outlined by O'Conner (1984). We also note three more passive participants (P3, P4, and P5) who share content visually but do not frequently talk, and also one participant (P2) who assumes the role as meeting facilitator. This single display group (B2) ultimately made three insights and discovered 9 out of the 12 possible key facts.

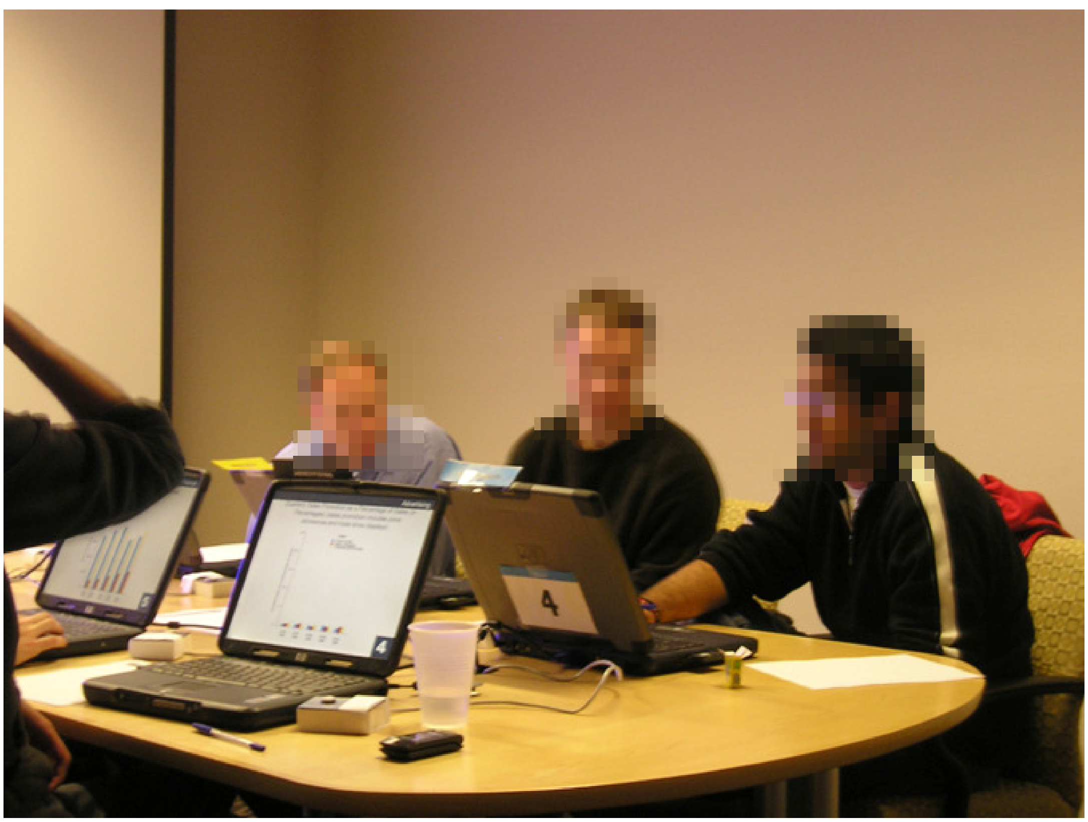


Figure 41: Single-display condition group breaking down subgroups based on the sides of the table.

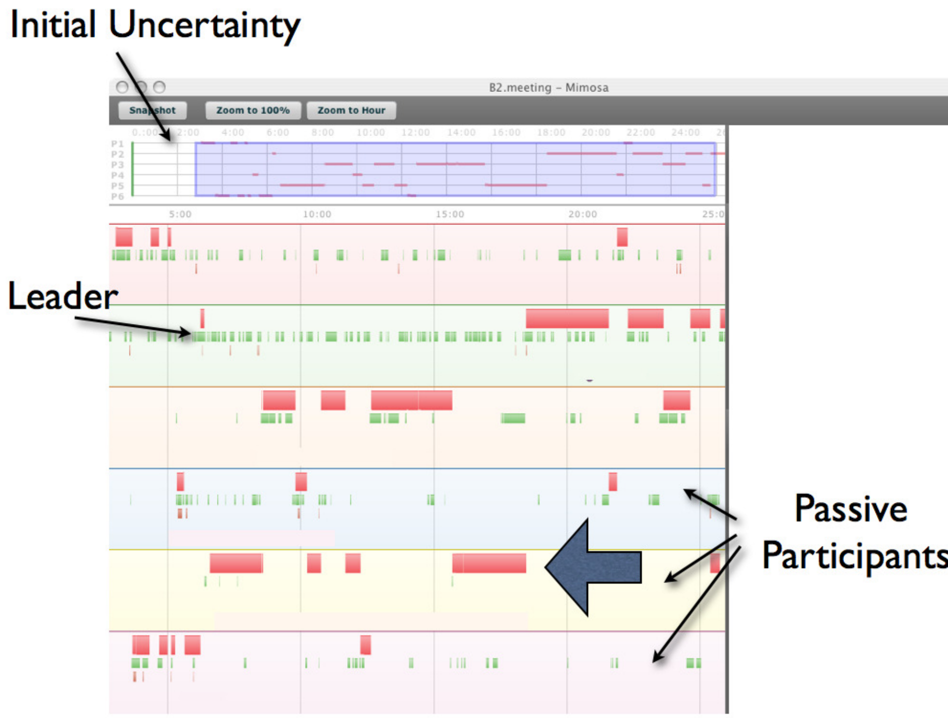


Figure 42: Examples of social aspects of the meeting process.

6.3 Satisfaction

We explored satisfaction with the collaboration process via surveys and interviewing. As illustrated in Table 11, participants in the side-by-side condition ranked their satisfaction with the meeting process significantly higher on a 7-point Likert scale than those in the single-display condition ($F(2,103)=3.610$, $p=.031$). (Note that one participant failed to answer that survey item).

Overall, individuals gave positive feedback regarding the quick access to sharing content via shared displays. One participant commented, "*The projector allowed open discussion on the available information*" Another stated, "*It was nice, very fluid. It allowed sharing with zero overhead.*" Another individual stated that the shared displays facilitated "*rapidly direct[ing] the group to slides for comparison.*" A few negative comments centered primarily upon an occasional lag in the switching device.

When we asked participants their thoughts about the shared display configuration, participants had consistently different comments in each display configuration. Single-display users desired a second display to facilitate comparisons amongst the data. When asked of what additional resource would have improved the group decision-making process, 16 participants remarked "*side-by-side displays*." A few individuals went beyond dual displays, desiring "a *shared desktop so I could 'edit' things on someone else's screen*" or a "*communal whiteboard that could be edited from each person's workstation*." Four participants in groups that did not use the whiteboard also remarked that the whiteboard would have been useful to organize thoughts, but were unsure why their groups did not use it.

Participants in the side-by-side display participants indicated a desire to have more than two displays: "*We need more than two screens [to explore this]….we need like six."* The desire for more displays was frequently echoed in the post-experiment surveys as a way to further assist groups: "*Two screens is not enough; 4-6 might be better."* One individual went even further, stating that "*only being able to compare two people's slides at a time*" inhibited the generation of ideas within the group. Others remarked that the side-by-side configuration had the benefit of "*show[ing] correlation between two ideas and give supporting evidence towards similar ideas."* However, one participant did note that drawback of the side-by-side configuration was potential ambiguity: "*You were not sure which display someone was talking about."*

Opposing display condition participants indicated finding utility in having multiple displays, but there was an overwhelming desire to have the two displays on the same wall. This finding supports Su & Bailey's guideline that displays should not be orthogonal to each other (Su and Bailey 2005). One participant remarked that, "*what was distracting was having the displays on opposite sides of the table, making it harder to compare data,"* taking away from the meeting experience. A majority of individuals in the dual-display condition (80%) remarked during interviews that they did not like looking back-and-forth between the two displays, however, two participants noted that they were able to determine which display people were talking about simply by seeing where people's heads were turned to, illustrating that location of shared displays can be used to reduce the ambiguity of determining which display an individual is referring to. However, as noted in the previous section, gesture rates towards the shared displays between the two multiple display conditions did not differ significantly.

6.4 Discussion

The presence of multiple displays influenced how groups completed the sense-making task in our study, supporting Su & Bailey's findings that different configurations of large displays impact users differently on their tasks (Su and Bailey 2005). Our initial research questions sought to examine whether a second shared display resulted in an improvement to the meeting process (RQ2) and whether a controlled laboratory study effectively evaluate aspects of collaboration with respect to shared displays (RQ3). Our study provides results that support several of our hypotheses, namely:

- The additional second shared display improved collaboration by providing opportunities to compare and contrast materials.
- Participants in a multiple shared display condition (side-by-side) were more satisfied with the collaboration process than those in a single display configuration.

- Our controlled study design—that of individuals performing a sensemaking task—combined with a key fact and insight-based evaluation methodology provided an effective way to evaluate collaboration with respect to multiple shared displays.

We did not find evidence to support our hypothesis that a second shared display would increase the potential for parallel work to occur during the collaboration process, nor did we find quantitative evidence that groups using the multiple shared display configurations identified more key facts than groups using a single shared display. However, we do offer qualitative evidence that groups in different display conditions collaborated differently.

We note, however, that due to the controlled nature of this empirical study, results cannot be easily generalized to other situations and follow-on work needs to further explore these findings—for example, how would performance results change if the groups consisted of 10 individuals? However, in conjunction with other work regarding display placement, such as Wigdor *et al* (Wigdor, Shen et al. 2006) and Su and Bailey (Su and Bailey 2005), designers can use our results to inform the creation of future collaborative spaces when considering placement of shared displays. In particular, we offer several themes supported by the findings in this paper when supporting a sensemaking task with shared displays:

Theme 1

Multiple-shared displays offer opportunities for individuals to engage team members.

Multiple shared displays impacted the social protocol of the meetings by allowing for new ways for individuals to interject or segue the group discourse. Generally speaking, groups in the side-by-side shared display conditions flowed and interacted more smoothly than groups under the other two conditions. In particular, we note that groups under the single-display condition often had an erratic flow where individuals would abruptly talk about their data instead of sharing it visually. This was partially due to social factors—did an individual deem their insight was important enough to requisition control of the large display? This is a relevant concern to many meetings, since implicit or explicit power relationships (Owens 2000) may impact how likely someone is to request "ownership" of a shared display.

When an individual shared content on one display in a multiple display setting, the second display could be used by another participant. A second shared display thus allows shyer group members a lightweight method to introduce their content into the group analysis, also illustrated in Figure 43. Conversely, multiple shared displays also

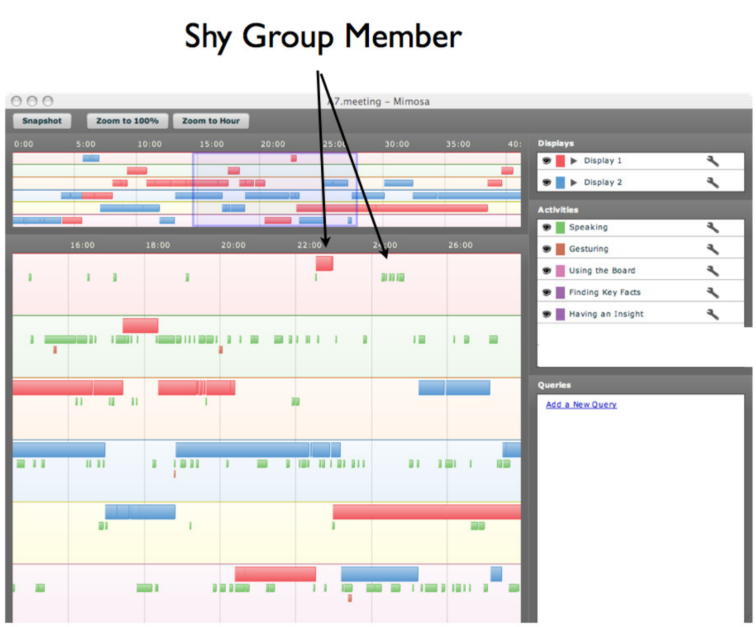


Figure 43: Example of shy group member using shared display to enter conversation.

provide a mechanism to prevent one individual from dominating the group conversation.

Our results parallel similar findings within online communities research. Sproull and Kiesler note that electronic communication can give a voice to the voiceless—allowing a "peripheral" individual the opportunity to contribute to a larger discussion (Sproull and Kiesler 1991). Furthermore, Sproull and Kiesler also note that new communication technologies tend to have two effects on organizations. First-level effects are the anticipated benefits of introducing new technology into an organization. For example, in our studies, one would expect the addition of a second shared display to have a first-level effect of facilitating more information to be shared simultaneously. Second-level effects result when a new technology influences how individuals pay attention to their environment or depend on each other. As a result of second-level effects, social roles may change. Our finding of multiple shared displays engaging more passive individuals is an example of this phenomenon.

Hudson and Bruckman also note that several studies indicate that some students are more willing to participate in online educational conversations than in the classroom (Hudson and Bruckman 2004). Note, however, that Hudson and Bruckman use different terminology; they refer to an individual as *participating* if he or she actively takes the role of both speaker and listener at some point, while *engaging* simply refers to mental concentration. In our analysis, we use the term *engage* to refer to individuals contributing information to the group.

Hudson and Bruckman also propose using the Bystander Effect (Latané and Darley 1968) as a lens to understand whether or not individuals will participate in a group activity (Hudson and Bruckman 2004). The Bystander Effect refers to the infamous case of Kitty Genovese in New York City, where Ms. Genovese was attacked and murdered for thirty minutes in the presence of dozens of witnesses (Rosenthal 1964). Simply put, the Bystander Effect is social phenomenon where individuals are less likely to intervene in a situation when others are present due to factors of self-awareness, social cues, and blocking mechanisms.

Using Hudson and Bruckman's framework, we can categorize how multiple shared displays facilitated more passive participants in contributing to the group sensemaking process. Although we did not test for self-awareness or confidence of participants, it was clear from reviewing videotapes of sessions that some individuals were shyer than others and did not speak as much as other participants on their teams.

Generally speaking, a person with higher levels of self-awareness, such as a shy individual, is more likely to be concerned with others judging him or her. For instance, Hudson and Bruckman report on a situation where one highly self-aware participant contributed more in an online environment because she did not feel the same sense of a judging audience. We hypothesize a similar phenomena is occurring during the controlled studies; by placing content on a display not currently being used, an individual perceives the groups' attention is shifted towards the display and not on the individual person. When only one shared display is available, we hypothesize a person is more self-aware of the need to interrupt conversation verbally to introduce information, or decide when it is appropriate to take control of the shared display away from someone else.

Furthermore, the ability for multiple shared displays to engage shyer participants may be explained by social cues and blocking. During a typical meeting, social norms dictate that only one person can speak at time. Likewise, when a single shared display is present, only one individual can share information visually at a time. Thus, when an individual is sharing content on a single display or someone is speaking, other participants are essentially blocked from sharing content or talking at the same time. In the multiple shared display conditions, blocking is reduced because two individuals can essentially share the floor at the same time by having content displayed to the group simultaneously.

Theme 2

Placing multiple shared displays side-by-side offers performance benefits as opposed to placing displays at opposing ends of the table.

With respect to display condition, our results indicated that groups in the side-by-side shared display configurations were able to have more insights than those groups in the opposing shared display configuration. Examining the videotapes and transcripts yielded more exploratory comparisons of information when the dual displays are side-by-side. Interestingly, groups under the opposing-display configuration spent significantly more time showing slides on the shared displays that contained key facts in comparison to the groups in the other two conditions. Despite being exposed to the necessary information for long periods of time, these groups were not able to have insights as often.

Su and Bailey noted that displays should be positioned at a 45-degree or lower angle relative to each other, noting that an orthogonal configuration of two displays correlated to lower performance on task times. Similarly, in this paper, the opposing display configuration tended to have lower performance in gaining insights (as shown in Figure 27 and Figure 32).

However, the opposing display configuration did offer several unique characteristics. The location of these displays gave participants an additional cue to determine which display another group member was looking at (i.e., Figure 40), alleviating some of the ambiguity in determining which display had the group's attention. However, this did not impact the rate of pointing gestures between the two dual display conditions. The opposing dual display configuration, however, appeared to promote eye contact with individuals as they changed attention focus from one side of the room to another. Our camera angles did not allow for us to easily or accurately code for this, but eye-contact represents a potential metric to gauge engagement in future studies.

Theme 3

A insight-based evaluation offers a useful way to evaluate team collaboration under controlled circumstances.

Evaluating how technology affects collaboration is particularly challenging, in part by the many differences in how individuals work together as a team, but by also establishing metrics to compare performance. In our study, we created an insight-based evaluation to compare how teams accomplished a sensemaking task. Typically in collaborative technology research, evaluation tasks are kept simple. For example, GDSS researchers frequently use creative and decision-making tasks (Fjermestad and Hiltz 1998). Recent HCI research on collaborative systems, such as investigating display placement under controlled settings such as (Su and Bailey 2005; Wigdor, Shen et al. 2006) used performance tasks (i.e. clicking targets) in their evaluations.

Performance tasks and brainstorming exercises are fairly easy to implement and evaluate, which may be attractive for researchers, however, they only offer information about one specific task type. Collaboration typically includes a variety of other tasks and combinations of tasks, many of which may be information-centric or complex (McGrath 1984). Our work contributes a new way to evaluate collaboration amongst multiple individuals performing a sensemaking task where information may be overwhelming at first (Thomas and Cook 2005). In our field studies, we noted sensemaking was an activity occurring at both companies during their day-to-day operations. However, as noted in Saraiya *et al,* an insight-based analysis is labor intensive and requires domain experts (Saraiya, North et al. 2005), and it is still difficult to control for variance in how well randomly assigned individuals will work together.

Theme 4

Side-by-side shared displays offer similar cognitive benefits to using a single shared display in conjunction with a whiteboard.

While Theme 2 explores the performance benefits of the side-by-side dual display configuration over the opposing dual-display configuration, we also most note the lack of significant difference in performance results for the side-by-side dual display groups against the single-shared display group. We noted that four of the six single-display groups used the whiteboard to record trends and key facts (i.e. Figure 44), suggesting that meeting space users will adapt collaboration strategies to use the technologies, both analog and digital, provided within a space.

We hypothesized that the additional screen shared screens would facilitate comparison of the data, resulting in more key facts being observed and more insights being made. Therefore, we were surprised by the lack of a significant difference between the average number of insights made by the side-by-side and single display groups

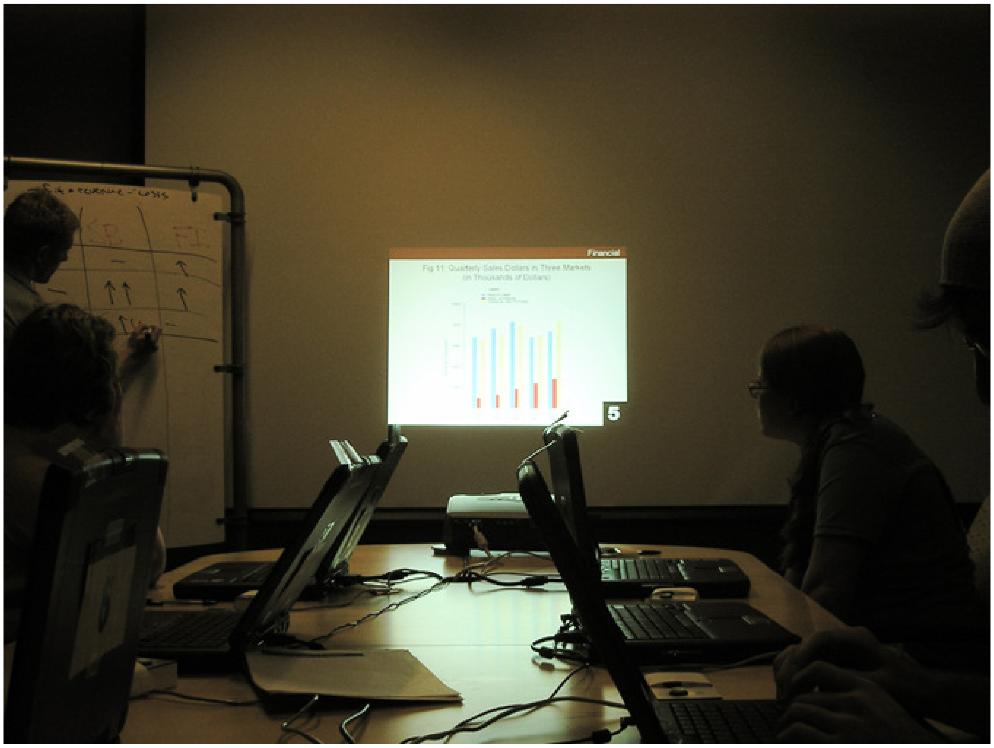


Figure 44: Single-display condition team using whiteboard.

considering that other findings strongly suggest that the patterns of collaboration differed drastically amongst the different groups.

For example, Figure 30, Figure 31, and Figure 32 showed very different plots regarding the percentage of insights made by the different display condition groups. We also noted how raters analyzing the transcript of the experiment sessions remarked that the side-by-side display groups tended to have higher-level discourse while groups using the single display were typically more abrupt. Therefore, it seemed logical that the smoother collaboration styles would correlate to an advantage in having insights, although the only significant difference was the average number of insights obtained between the two multiple shared display conditions.

We also noted that groups under the single display condition used the whiteboard more frequently than the other two display conditions. The single display groups used the whiteboard to organize thoughts, trends, and themes emerging from their analysis, as illustrated in Table 10. Interpreting the whiteboard usage through distributed cognition (Hutchins 1995), and in particular Salomon's classification scheme (Salomon 1993), we argue that the white board served as a physical object off-loading the cognitive efforts of the team exploring the data set (illustrated in Figure 34). For those in the side-by-side display condition, team members appear to be performing an act of shared cognition by viewing side-by-side comparisons of information, data, and slides. Conversely, only two groups under the opposing-display used the whiteboard. Therefore, due to the disjoint location of the opposing displays, team members were not able to share in cognition as well as their counterparts under the side-by-side condition.

Furthermore, we note the opposing dual-display group members spent significantly more time showing slides containing key facts on the shared display than the other two group conditions support this theory, yet did not demonstrate any substantial performance gains. Considering this finding from a distributed cognition approach, four of these groups did not use the whiteboard to offload the cognitive efforts of drawing comparisons and correlations amongst the data set (shown in Table 10). They also did not have the added benefit of shared cognition for side-by-side analysis. Therefore, these groups spent more time on these slides recalling information and previously discovered key facts rather than drawing logical connections between them to obtain insight.

6.5 Experimental Limitations

Experiments, such as the controlled study presented in this chapter, are a way of systematically testing assumptions under controlled settings. However, they offer potential challenges for generalizing and interpreting results. In this section, we discuss several factors that may influence interpretation of the results we presented in this chapter.

6.5.1 Experimental Limitations: External

As with the majority of laboratory studies conducted under controlled settings, we caution against over generalizing results to other situations. In our controlled study, we used a specific sensemaking task that is just one type of activity that occurs during meetings. We note that different meeting activities or tasks may result in different findings. We also note that how teams use the shared display(s) and whiteboard may vary according to task complexity; it is conceivable that a team may be more likely to use these resources for more complex problems, for instance, to make group notes or summarize and highlight key points.

In our studies, we characterized observed sensemaking activities using McGrath's task framework (McGrath 1984). However, the study of how individuals collaborate is a widely explored research area within the business and management communities and we acknowledge other evaluation frameworks exist for categorizing teamwork. For example, McFadzean offers a five-level classification scheme for classifying groupwork considering elements of how much focus is placed on the task, interpersonal interactions, and responsibilities of meeting participants (McFadzean 2002).

Furthermore, the majority of our participants were undergraduate students at a large engineering school. Being undergraduate students, many participants did not have substantial management experience. Although formal business educational experience was not required to successfully solve the primary task, familiarity with management and business concepts might have impacted participants' strategies during the sensemaking task. As undergraduate students, our participants also did not have much formal group experience outside of course projects. It is conceivable that established groups of individuals with substantial meeting experience might have approached the sensemaking task in different ways. For the intents of our controlled study design, it was impractical to find existing work groups to gain enough participants for each display condition.

6.5.2 Experimental Limitations: Internal

We took specific measures to minimize the effects of factors other than the display placement and location on how the teams collaborated. For example, individuals were randomly assigned to roles within the study, scripts were used so that all participants received the same instructions, and experimentation occurred in the same location. Still, we acknowledge several factors that may have influenced findings.

Maturation: Our study participants were largely undergraduate students at a large engineering school. We acknowledge that the natural aging process of experiences may lead to changes in how individuals approach sensemaking or interact with teammates. Since our study required running teams of six individuals, it was challenging to recruit a large amount of experienced individuals for all three display conditions.

Selection: Recruitment for our study used an experimental subject pool at a large engineering school. Thus, individuals participating were doing so for course credit and may not have been motivated to perform well. To ameliorate this problem, we offered a $20 per person bonus for the team that correctly solved the primary sensemaking task in the shortest amount of time. However, we cannot be certain if individuals were truly motivated to perform well.

We did not pre-screen participants for this study for educational background and leadership experience. However, Table 6 suggests that the educational backgrounds of participants were roughly distributed across the three display conditions. We also acknowledge that testing occurred at different times of the day and might have impacted the mental capabilities of participants. Furthermore, we assigned each participant randomly to a role within the study. Since we did not pre-test for leadership experience, we are unable to determine if more experienced leaders were inadvertently placed in certain roles.

6.6 Controlled Study Conclusions

Our empirical study showed that presence and location of multiple shared displays influenced how groups perform a collaborative analysis on an analytical, sense-making task. Groups using the side-by-side dual shared display condition were able to identify significantly more insights while collaborating than those in the opposing dual-display condition even though groups in the opposing dual-display condition spent significantly more time showing the slides containing the key facts on the shared displays. In addition, people in the side-by-side dual display condition indicated a significantly higher rating than individuals in the single display condition for satisfaction of the meeting process and how well the teams collaborated. We also provide qualitative evidence for previously undocumented ways groups use multiple shared displays to collaborate, engage others, or organize information content, and evidence that the presence of multiple displays changed social protocols in the meeting.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

In this thesis, we investigated the impact of increasing the number of shared displays on meeting practices through empirical fieldwork and controlled laboratory studies. In our fieldwork, we investigated how two companies used shared displays before and after we placed a second shared display into their meeting rooms, with specific attention on which technologies individuals used during the meetings. We are not aware of other field studies of non-specialized shared display usage that consider context of use. For example, Newman *et al* longitudinally studied a single meeting space to examine the application of software services to share displays, but the authors did not explicitly characterize the situations in which their enhanced display capabilities were used. Conversely, Huang *et al's* longitudinal work focused on a highly specialized interactive large display and multiple-display setting, MERBoard.

Rather, in our approach, we examined how employees from two companies' used the shared displays within their meeting spaces and we also examined how existing technologies were deployed and used. Furthermore, halfway through the 8-week-long observation process, we added a second shared display to each meeting space and observed how groups approached, adopted, and used the new technology. We identified several tasks that appeared to benefit from the presence of multiple shared displays and chose one, sensemaking, to further explore under a controlled laboratory setting.

In the controlled study, we investigated the impact of presence and location of a second shared display on teams collaborating on a sensemaking task and captured the low-level actions that occur during collaboration. We evaluated performance of teams collaborating by using an insight-based methodology, where we examined when teams observed key facts and made logical connections (i.e. insights) amongst them. We used descriptive and inferential statistics in our initial analysis of the data we collected. To more rigorously explore the interactions between individuals, data, and the shared displays, we built Mimosa, a visual analytical tool that combines information visualization with data analysis. Specifically, we designed Mimosa to support an individual in understanding relationships within datasets containing a large number of elements (in this study, datasets containing between 8,000 and 61,000 elements).

We identify contributions to the HCI and Information Visualization communities in the following sections.

Contribution 1: *The presence and location of multiple shared displays impacted how teams of individuals performed a sensemaking task with respect to performance, collaboration, and satisfaction. In addition, multiple shared displays afford opportunities to engage more passive team members in group discussions.*

Our field study analysis indicated that sensemaking and peripheral information tasks were facilitated by multiple shared displays. We explored sensemaking tasks in more detail during our controlled study, finding in particular that side-by-side shared displays facilitate direct comparison of information, a task fundamental to sensemaking. As a result, users within the side-by-side display condition ranked their satisfaction for how their groups reached their solutions during the sensemaking task significantly higher than individuals in the opposing dual display or single display condition. Furthermore, users in the side-by-side display condition ranked their groups' overall collaboration efforts significantly higher than groups in the single display or opposing dual display conditions.

We also reported that participants were able to make significantly more insights when the dual displays were placed side-by-side than on opposing walls. Although side-by-side dual display and single display groups were not significantly different, we note the very different plots of insights made in relation to the number of facts each group (Figure 30, Figure 31, Figure 32) indicate that groups in the three conditions collaborated in very different manners. Furthermore, all groups in the side-by-side dual display condition were able to make at least one insight, and the only group (A2) that observed all the insights, as defined by our experts, was also in the side-by-side display condition. Conversely, each of the other two display conditions contained two teams that that never made an insight, even though they observed the facts they needed to do so.

We also provided evidence that multiple shared displays offer a way to engage passive team members in the group collaboration. In his recommendations on good meeting practices, Wolf specifically recommends encouraging the expression of viewpoints of all individuals and inviting individuals who have not spoken much to voice their opinions (Wolf 1994). When only a single shared display is present and being used by another team member, a passive participant must negotiate amongst social protocols and power relationships—is the content that the passive individual wishes to share important enough to merit taking control of the shared display away from someone else? When multiple shared displays are present, an individual can take control of the display that is not currently being used, or the display that currently does not have the groups' active focus.

In times of increased competitiveness and challenging economic climates, companies are seeking new ways of boosting productivity. Our studies show that individuals were more satisfied with the meeting process when using a side-by-side dual shared display configuration. Since research indicates that perceived meeting effectiveness is correlated to job attitudes and well being (Rogelberg, Leach et al. 2006), a side-by-side share display configuration offers benefits for organizations. In addition, we note that the only team able to identify all the insights defined by domain experts used the side-by-side multiple display configuration, and all teams using the side-by-side multiple display configuration were able to make at least one insight.

Contribution 2: *Our insight-based evaluation method provides a new way to analyze teams performing sensemaking tasks. Furthermore, by using our method, we show that the number of insights made by a team is positively correlated, in a nonlinear relationship, with the number of key facts obtained.*

Our evaluation methodology, that of measuring the number of insights made while a team performs a sensemaking task, represents a contribution to the HCI community as an innovative way to evaluate collaboration. As noted earlier, many existing studies evaluating collaboration use relatively simple brainstorming or planning tasks. However, as we reported in our field studies, many meetings consist of several different tasks. In particular, we observed sensemaking as an activity that involved multiple tasks that was also facilitated by multiple shared displays.

In our insight-based evaluation method, we tasked teams to determine why a fictional company's profits are decreasing while sales are increasing. We structured the distribution of information to participants such that information needed to be shared with other team members in order to correctly identify relationships between the data. Our insight-based evaluation technique allows us to quantify the rates at which teams uncovered key facts and made insights between facts.

Furthermore, our insight-based evaluation method provides additional knowledge about the sensemaking process. In particular, our findings illustrate a positive correlation and nonlinear relationship exists between the number of key facts observed by teams and the number of insights made by the team. This relationship holds for any team that makes at least one insight and further holds across display configurations.

Chang *et al*. hypothesized a similar nonlinear, positive correlation between the amount of knowledge obtained by an individual and the probability of the individual having spontaneous insight into a solution (Chang, Ziemkiewicz et al. 2009), but do not provide any data to justify their claim. The authors define spontaneous insight as being different from ordinary problem-solving, referring to the "a-ha moment" associated when an individual is suddenly able to understand a solution to a problem. Our evaluation method facilitated measuring insight as an objective way to examine performance.

We also note that our insight-based analysis indicated that a majority of teams reach a point of information saturation where observing subsequent key facts will not result into additional insights being made. In fact, only the only group that made all the insights as defined by our domain experts used a side-by-side display configuration.

Contribution 3: *We present Mimosa to create a visual representation of the activities associated with meeting processes. Furthermore, Mimosa is an example of a visual analytics system, an emerging research area combining information visualization with analysis tools.*

While researchers have developed visualizations of other aspects of work, such as scheduling or occupancy patterns, we are unaware of research creating visual representations of meetings. A substantial amount of research within the management community investigates practices occurring during productive meetings, therefore it is surprising that little research has visualized the events occurring during a meeting, such as when individuals speak, gesture, or use technology. Visualizing data often conveys relationships between data elements, or patterns of activity that may not be apparent in traditional data analyses, such as using inferential statistics.

We developed Mimosa as a visualization tool to investigate the data we acquired during our controlled study. Specifically, Mimosa allows a user to explore the association between the low level activities occurring during the meeting process, such as who was speaking at what moment or what information was being shared. We designed Mimosa using color and icons to represent meeting events and activities and also to facilitate user exploration of the dataset in more detail while still maintaining context of the overall meeting process.

We also combined the visual representations of meeting activities with the ability for a user to perform data analysis queries, making Mimosa an example of a visual analytic system. Thus, Mimosa facilitates end-user sensemaking through deep and iterative exploration of the data set. For example, a user may visually spot two data events occurring at the same time at one particular moment. Using Mimosa's query tool, the user can see any other instances where the two data events occur at the same time, allowing the user to confirm whether or not the correlation was significant. In our analysis of the controlled study, we initially discovered an instance when a participant gestured towards a shared display at the same time he had an insight. By using Mimosa's query capabilities, we were able to highlight all instances when insights were made at the same time a gesture was made and discover that gestures not only occurred when an individual made an insight, but could also occur either immediately before or after the insight was made. Mimosa allowed for us to see that a flexible relationship between having an insight and gesturing.

Contribution 4: *Social aspects of meetings relate to routines associated with technology use.*

HCI researchers often focus on developing technical infrastructures or new interaction techniques when designing for collaborative environments. There are numerous everyday experiences with technology in meetings that can arguably be improved upon, such as connecting a laptop computer to a projector.

However, technology researchers often do not consider the social aspects of the meeting process, despite research within the management community indicating that the meeting process shifts between social-oriented and task-oriented activities. Task-oriented patterns of behavior involve completing the issue at hand, while social-needs patterns involve releasing tension and addressing solidarity (Poole, Seibold et al. 1985).

During our field studies, we noted that approximately 75% of individuals connecting their devices to a shared display did so within the first few minutes of arriving into a meeting space, a phase of the meeting process we termed “arming.” The act of arming devices—connecting power, data, peripherals, and video cables—occurs during a part of the meeting process that is inherently social; as individuals physically enter a meeting room, they tend to engage in small talk such as asking about a co-worker’s recent vacation or someone’s spouse. This is a way for individuals to transition into the meeting the domain.

The relatively low cognitive load of arming devices (i.e. plugging in cables) does not hinder a meeting participant in engaging in social aspects of the meeting process; it is certainly not very difficult for most individuals to connect power and video cables while carrying on a conversation. As technology designers seek to improve the ways individuals use technology in collaborative settings—such as connecting to shared displays—we argue that designers ought to consider the social aspects of the meeting process, striving to support and enhance existing practices rather than using technology to fundamentally alter the medium. Other researchers, such as Miner, also argue for the inclusion of social needs when designing collaboration assistive technologies (Miner 1979).

7.1 Thesis Statement

The program of research presented in this dissertation is a systematic way of exploring the impact of multiple shared displays on collocated collaboration work practices. We show evidence when multiple shared displays influenced the method in which groups collaborated (i.e. offloading some mental effort by allowing direct comparison of data) as well as improving satisfaction of the meeting process. Furthermore, we showed how multiple shared displays allow for opportunities to engage more passive members of the group, by providing a lightweight mechanism to share data without having to vocally interrupt the conversation at hand.

Thus, findings from the longitudinal fieldwork and controlled study provide evidence to support our thesis statement:

> *Multiple shared displays showing augmenting information in a collocated meeting environment can A) result in same or improved collaboration and communication amongst meeting participants, and B) result in same or improved satisfaction with the meeting process*

In other words, across studies, individuals who used multiple shared displays performed as well or better as those who participated in a single-display condition. We also offer evidence that multiple shared displays changed the nature of collaborative activities being performed. Furthermore, users in the dual side-by-side display condition self-ranked significantly higher for satisfaction with the meeting process, and qualitative interviews from the longitudinal study indicated perceived benefits of additional screen real-estate.

7.2 Future Work

In this section, we discuss potential future directions for research in both naturalistic and experimental conditions. First, we outline extensions to the fieldwork studies we conducted. Second, we describe extensions to the controlled laboratory study. Finally we describe enhancements to the Mimosa visualization tool, currently underway.

7.2.1 Fieldwork Extensions

We present two avenues for future field study research to further explore the impact of multiple shared displays on collaboration practices. In the field studies described in Chapter 3, we found evidence that the existing method by which individuals connect to shared displays during meetings—that of physically connecting a video cable to a laptop computer—typically occurs during an inherently social part of the meeting process. We noted that the relatively low cognitive load associated with plugging in cables and turning on projectors facilitated individuals interacting with each other at the same time.

Arguably, plugging in video cables to devices is a “low-tech” approach to connecting to shared displays. Subsequently, several researchers have built sophisticated display-sharing systems utilizing software and wireless connections between devices and shared displays (Newman, Ducheneaut et al. 2006; Biehl, Baker et al. 2008; Golovchinsky, Qvarfordt et al. 2009). We propose extending our existing work by longitudinally studying the impact of multiple shared displays on collaboration when teams use a software system to connect to shared displays in single, dual side-by-side, or dual opposing display configurations. Specifically, we will investigate if existing routines (i.e. device “arming”) change or adapt to the new technology, or if the dynamics of collaboration change.

We also propose a second extension to the fieldwork studies by studying additional contexts in which multiple shared displays can be used. In our field studies, we investigated two meeting spaces within the corporate environment where users had existing relationships with each other. In addition, social and business protocols were already well-established. Future work will explore different population domains, such as students assigned to a team for a semester-long design project. Typically speaking, students have not established meeting roles and protocols when assigned into a new team, providing an interesting population to study how meeting roles and protocols evolve in the presence of multiple shared displays.

7.2.2 Laboratory Study Extensions

We present three avenues for future extension of the controlled laboratory study presented in Chapter 4. First, similar to the extension proposed in Section 7.2.1, we plan on studying the impact of the presence of and location of multiple shared displays on groups performing a sensemaking task when individuals connect to shared displays using a software-based system. We noted in our field studies that the physicality of connections to shared displays was important for both troubleshooting and signaling purposes.

However, researchers have recently built several display-sharing software infrastructure and interfaces (Newman, Ducheneaut et al. 2006; Biehl, Baker et al. 2008; Golovchinsky, Qvarfordt et al. 2009), capitalizing on the increased deployment, reliability, and speed of wireless data connections. Our study extension seeks to explore whether software-based connections, combined with presence and location of shared displays, will impact how groups perform the sensemaking task.

Second, we propose extending the current study design with a fourth group condition where individuals perform the sensemaking task without having a shared display present in the meeting room. In our current study design, we omitted this condition for logistical reasons, noting that many existing meeting rooms already have one display. However, we have preliminary data for this new condition indicating that not having a shared display influences how individuals collaborate, namely placing more responsibility on each individual to synthesize their own data sets.

We also propose extending the current study design by removing the whiteboard from each of the three display configurations and studying changes on collaboration practices. We included a whiteboard in each meeting space configuration since they are commonly found in many existing meeting spaces. However, in Chapter 6, we noted many single display condition groups using the whiteboard to record trends and observations. We hypothesize that the whiteboard acts as a physical object offloading the cognitive effort of comparing information. To explore how shared cognition changes with the presence and location of multiple shared displays, we will extend our laboratory study by removing the whiteboard from each of the three display configuration.

7.2.3 Visualization Tool Extensions

Finally, we are implementing several additional enhancements to the Mimosa visual analytical tool. Our initial set of user-tasks focused on a user investigating patterns and correlations amongst the data for a *single* meeting. As we iteratively refined Mimosa, we recognized a need to support investigating patterns and correlations as well as running queries across *multiple* meetings. Currently, we are implementing these capabilities in Mimosa and hypothesize the ability to specify a query across multiple meetings will increase the efficiency of a user verifying correlations between data sets. For example, if a user notes that event *X* occurs at the same time as event *Y* during meeting *A*, a user can run a query to see the number of matches of event *X* and *Y* occurring simultaneously across all other meetings.

We are also currently implementing *query relaxation*, a phenomena where results that do not exactly match the query, but are similar, are presented to the end-user. This allows for establishing relationships between meeting activities that may have some variance in their temporal occurrence. For example, in our previous example, an individual notes event *X* occurs at the same time as event *Y* at a particular moment during meeting *A*. When the user runs a query to find other instances of event *X* occurring at the same time as event Y, query relaxation will also report instances when *X* and *Y* occur in close temporal proximity, but not necessarily at the exact same instant. We have begun the process of implementing query relaxation, noting the process is non-trivial. The main challenge in implementing query relaxation is to effectively minimize the number of false-positive and false-negative results returned to a user. Even a small number of incorrect matches to a query undermines the credibility of the analysis tool.

7.3 Summary

Collaboration is important in contexts other than corporate meeting spaces, such as education or research. However, across these disciplines, successful collaboration efforts support the sharing of viewpoints of all team members. In this dissertation, we illustrate instances when multiple shared displays engaged team members who might not have otherwise contributed, as well as provide evidence that side-by-side shared display configurations result in teams having significantly more insights when performing a sensemaking task compared to groups using an opposing dual-display configuration. Furthermore, participants using a side-by-side dual shared display configuration were significantly more satisfied with the meeting process and how their teams collaborated, in comparison to individuals using a single display. Thus, our research provides evidence that that multiple shared displays support team members in the coordination and synchronization of information during sensemaking tasks.

APPENDIX A

PRIMARY TASK MATERIALS USED IN CONTROLLED STUDY

This appendix includes the Microsoft PowerPoint slides used in the controlled study. Each participant was randomly assigned a consultant role and a laptop computer containing unique information on their slides.

A.1 Participant 1's Slides

Domain Research

Bonanza Paper Forms

Case Files

DIRECTIONS In this study, you are playing the role of consultants hired by Bonanza Business Forms Company. This company sells paper forms for three markets: small business, hospital, and financial institutions. During the previous three quarters, profits have steadily decreased while total sales were increasing. Bonanza's management cannot determine the cause of the declining profits, so that's why you've been brought in. The goal of the outside investigation team is to determine the cause of the company's problem using a series of business reports and to identify why the problem is occurring.

Each of you has a notebook computer placed in front of you. On each computer, various information graphics, charts, and text related to Bonanza Business Forms' business over the past few years are provided via slides within PowerPoint. Note that you may have different information on the laptop in front of you than others do.

Your goal, as an individual, is to look over the information on the laptop computer in front of you. Then, as a group, you need to make sense of the information provided to determine why Bonanza is losing money while sales are increasing.

To assist you, you may use any of the provided applications on the computer, such as the built-in calculator or text editor("Notepad"). Also, each laptop has the ability to display information on one of the projectors. To show the information on your laptop, simply press the button next to your computer. We will go through a brief demo of how this works when you have finished reading the directions.

Do not look at any slides until you are told to do so 1

Your Role:
Domain Research Consultant

For this meeting, you will play the role of an historian who has researched the the paper company's recent performance and industry. The following slides in this document provide data, charts, and figures related to the the company

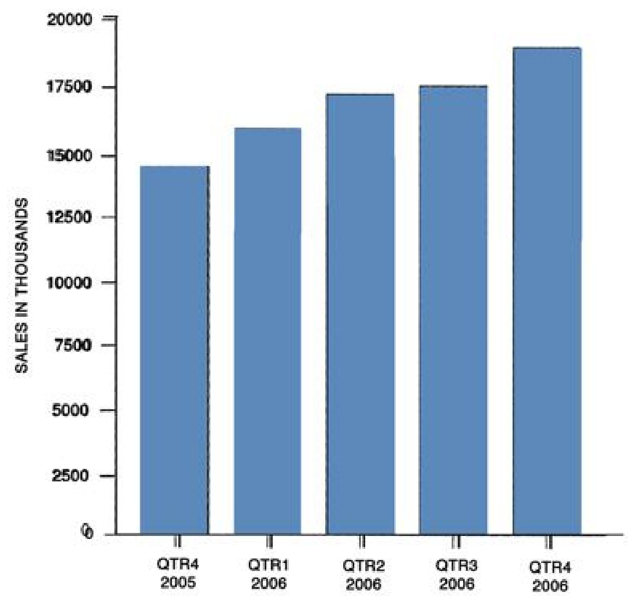
When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

Bonanza Paper Company

- Star performer on local over-the-counter paper stock.
- $70 million-a-year sales operation.
- Medium-sized business with 1,225 employees, total assets of $30 million.
- Founded to manufacture and market continuous business forms.

Fig 1: Total Quarterly Sales Dollars
(in Thousands of Dollars)



5

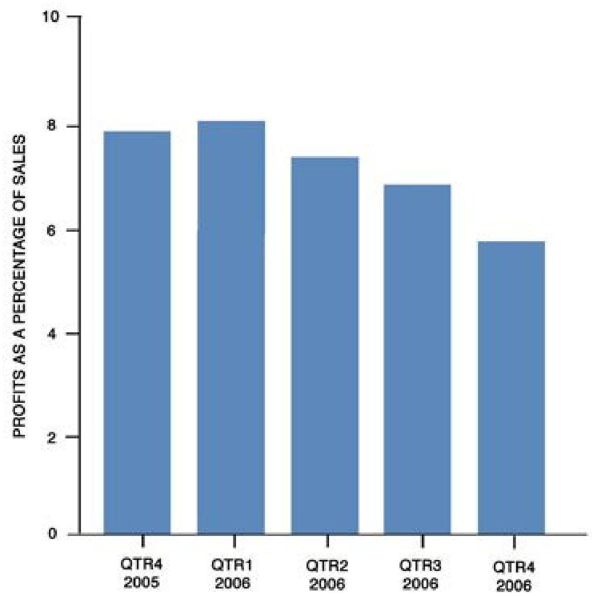
The Paper Forms Industry

- Business forms industry is comprised of 600 firms having a total of 800 production plants.
- Majority of firms are young, small, and highly specialized.
- Approximately 38% of the total industry sales are accounted for by the four largest companies.
- Bonanza Paper Forms ranks 16th largest firm in the industry (based on sales revenue).

4

Domain Research

Fig 2: Quarterly Net Profits as a Percentage of Total Sales (in Percentages)



6

A.2 Participant 2's Slides

Bonanza Paper Forms

Case Files

DIRECTIONS In this study, you are playing the role of consultants hired by Bonanza Business Forms Company. This company sells paper forms for three markets: small business, hospital, and financial institutions. During the previous three quarters, profits have steadily decreased while total sales were increasing. Bonanza's management cannot determine the cause of the declining profits, so that's why you've been brought in. The goal of the outside investigation team is to determine the cause of the company's problem using a series of business reports and to identify why the problem is occurring.

Each of you has a notebook computer placed in front of you. On each computer, various information graphics, charts, and text related to Bonanza Business Forms' business over the past few years are provided via slides within PowerPoint. Note that you may have different information on the laptop in front of you than others do.

Your goal, as an individual, is to look over the information on the laptop computer in front of you. Then, as a group, you need to make sense of the information provided to determine why Bonanza is losing money while sales are increasing.

To assist you, you may use any of the provided applications on the computer, such as the built-in calculator or text editor("Notepad"). Also, each laptop has the ability to display information on one of the projectors. To show the information on your laptop, simply press the button next to your computer. We will go through a brief demo of how this works when you have finished reading the directions.

Do not look at any slides until you are told to do so 1

Industry Trends

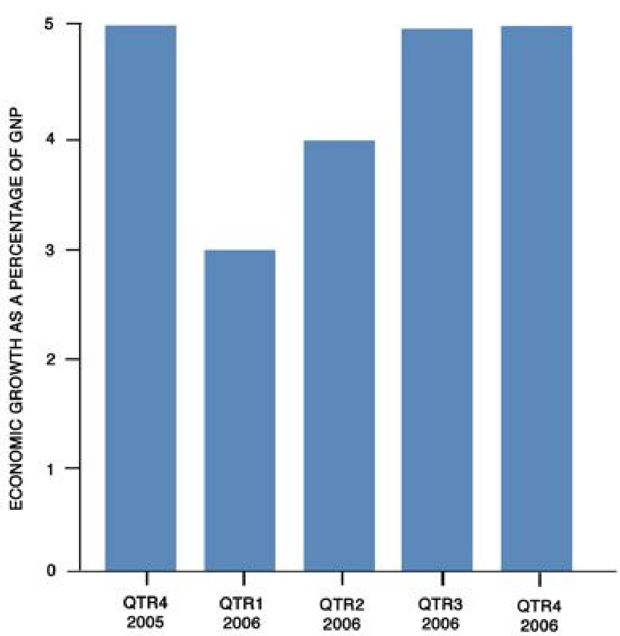
Bonanza Paper Company

- Internal investigation into decrease in profits.
  - Problem is NOT in production.
  - Evidence suggests problem is in marketing.
- Demand for business forms is closely tied to leading economic indicators, trends in the computer market, and new development.
  - Paperless technology is likely to increase competition in the business forms industry.

3

Industry Trends

Fig 3: Annual U.S. Industrial Economic Growth as a Percentage of Real GNP



4

Your Role: Industry Trend Consultant

For this meeting, you will play the role of a consultant who has researched trends within the paper forms industry domain. The following slides in this document provide data, charts, and figures related to this.

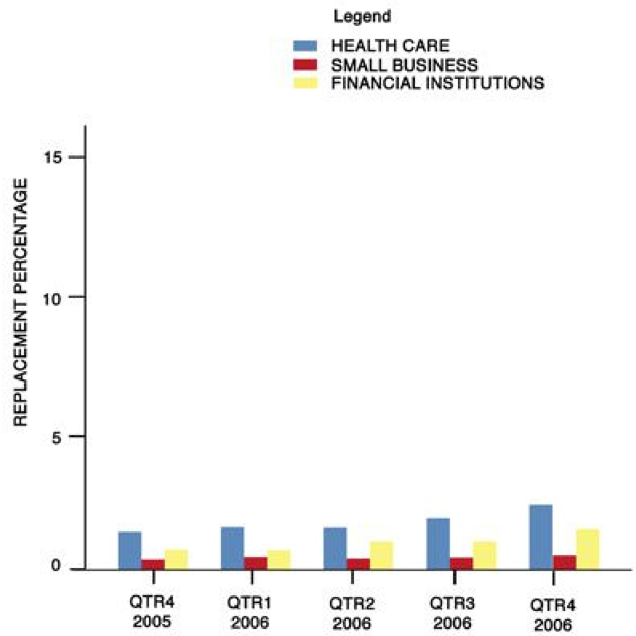
When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

Paper Forms Distribution

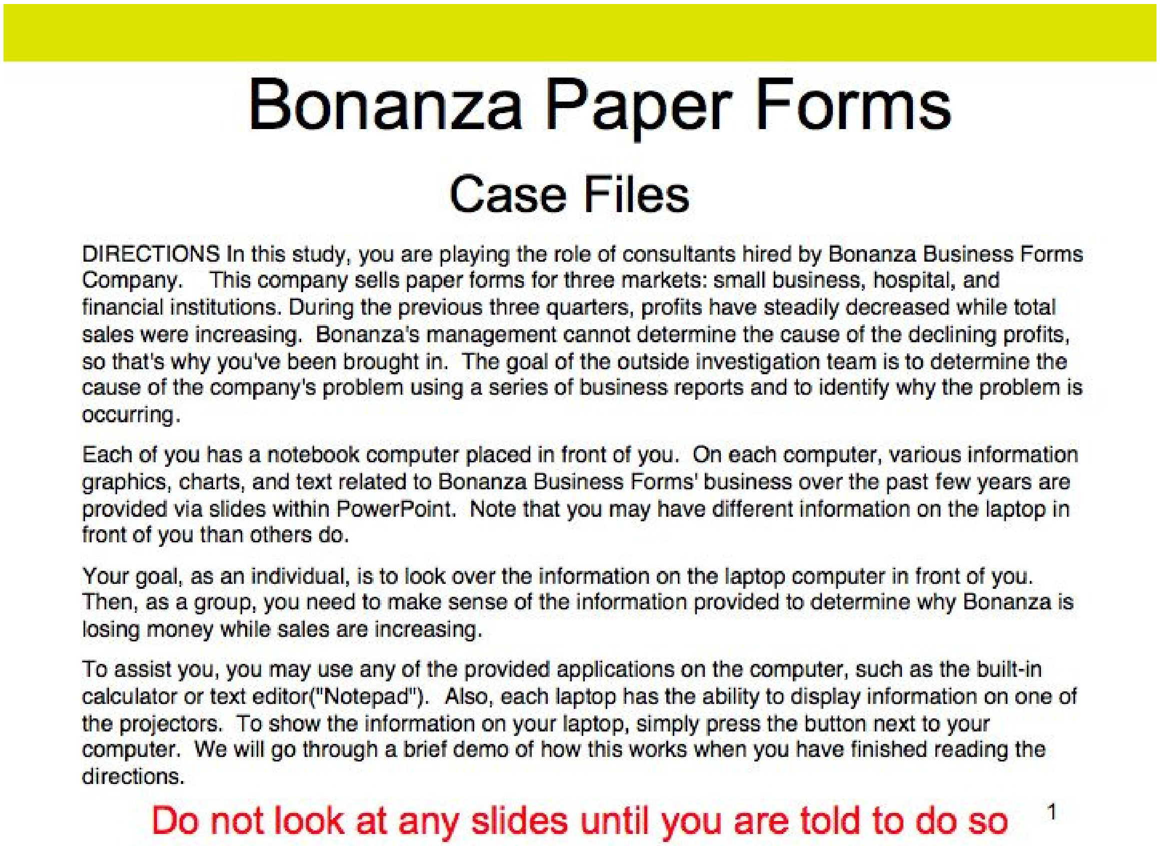
- Distribution Channels:
  - 1) independent distributors
    - Approximately 2000 full-time distributors exist in the market
  - 2) manufacturer's sales force
    - Bonanza is one of the few companies that markets directly using an internal sales force.
    - Belief that strong customer loyalty is developed through personal contact by the sales force.
  - 3) Retail, catalog/direct mail, Web site, and telemarketing operations

Fig 4: Replacement Percentages of Forms by Magnetic Media in Three Markets



5

A.3 Participant 3's Slides



Bonanza Sales Force

- Calls on all of the tree forms market Bonanza services: health care, financial institutions, and small business.
- Compensated through a commission based on their total sales.
- Size of the sales force has not changed substantially over the past five quarters (107-persons).

3

Your Role: Sales Force Consultant

For this meeting, you will play the role of a consultant who has researched the paper company's sales force. The following slides in this document provide data, charts, and figures related to this.

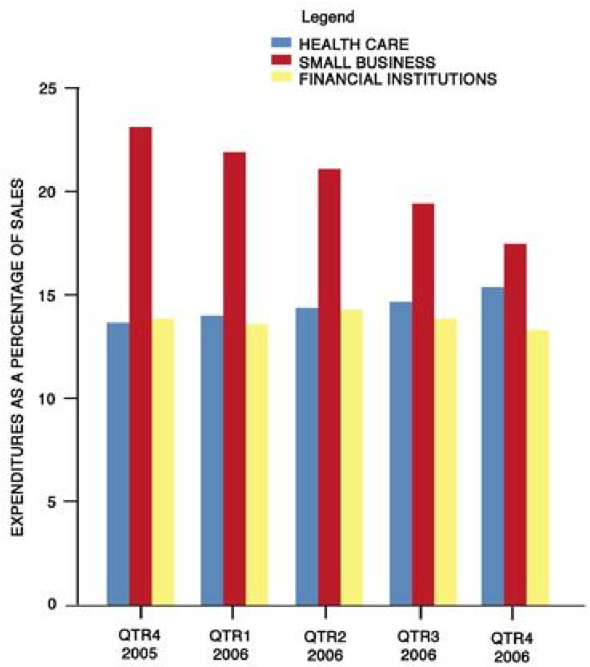
When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

2

Sales Force

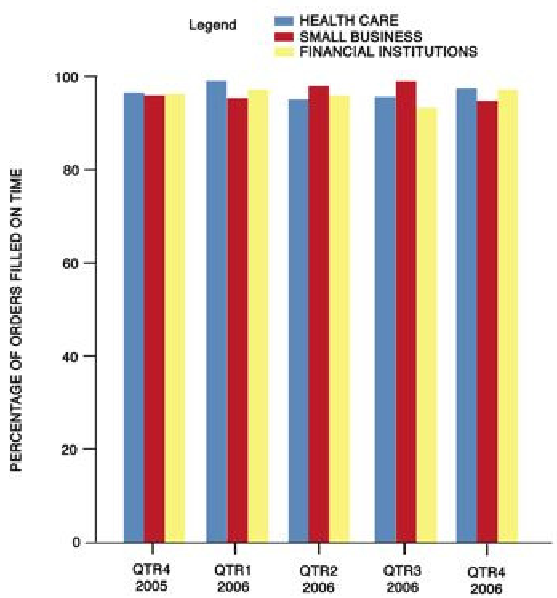
Fig 5: Quarterly Distribution Costs as a Percentage of Sales (in Percentages)



4

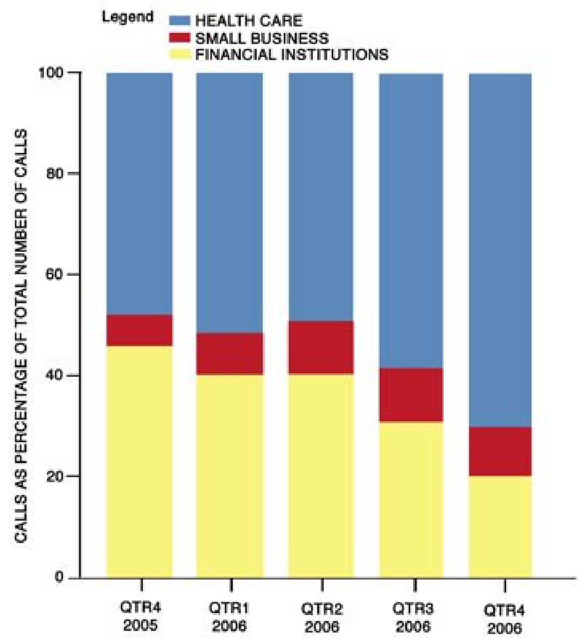
Sales Force

Fig 6: Bonanza Business Paper Form's Service Level in Three Markets Percentage of Orders Filled On-Time



5

Fig 7: The Number of Sales Calls Made in Three Markets as a Percentage of Total Number of Company Sales Calls



6

A.4 Participant 4's Slides

Bonanza Paper Forms

Case Files

DIRECTIONS In this study, you are playing the role of consultants hired by Bonanza Business Forms Company. This company sells paper forms for three markets: small business, hospital, and financial institutions. During the previous three quarters, profits have steadily decreased while total sales were increasing. Bonanza's management cannot determine the cause of the declining profits, so that's why you've been brought in. The goal of the outside investigation team is to determine the cause of the company's problem using a series of business reports and to identify why the problem is occurring.

Each of you has a notebook computer placed in front of you. On each computer, various information graphics, charts, and text related to Bonanza Business Forms' business over the past few years are provided via slides within PowerPoint. Note that you may have different information on the laptop in front of you than others do.

Your goal, as an individual, is to look over the information on the laptop computer in front of you. Then, as a group, you need to make sense of the information provided to determine why Bonanza is losing money while sales are increasing.

To assist you, you may use any of the provided applications on the computer, such as the built-in calculator or text editor("Notepad"). Also, each laptop has the ability to display information on one of the projectors. To show the information on your laptop, simply press the button next to your computer. We will go through a brief demo of how this works when you have finished reading the directions.

Do not look at any slides until you are told to do so

1

Sales Markets

Your Role:
Sales Market Analyst

For this meeting, you will play the role of a consultant who has researched the sales markets the paper company sells to. The following slides in this document provide data, charts, and figures related to this.

When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so 2

Sales Markets

Market Information

- Health Care:
  - Marketed towards hospitals, clinics, and pharmacies.
  - Over the past two years, become extremely competitive and difficult to establish any product differentiation between competitors.
- Financial Institutions
  - Marketed towards banks and insurance companies.
  - Competition is less fierce.
  - Moderate amount of product differentiation exists amongst competitors.

3

Sales Markets

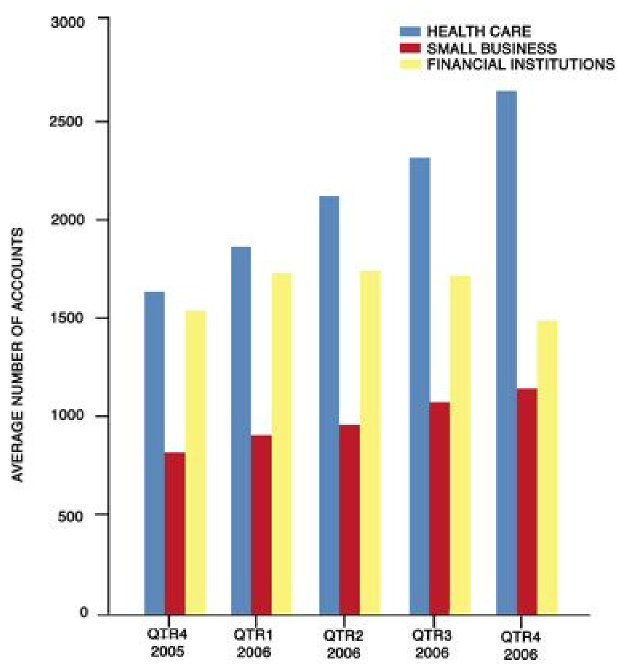
Customer Base

- In recent years, Bonanza has attempted to diversify its customer base.
- Expansion into the small business market.
  - Rapid growth in this segment due to proliferation of desktop and laptop computers.
  - Bonanza success in this area is mainly due to its unique product, laser-cut forms for easy tearing.

4

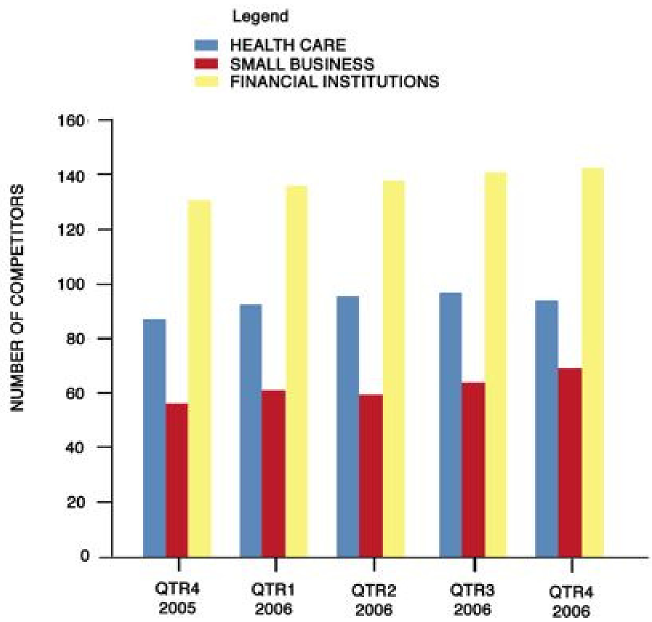
Sales Markets

Fig 8: Bonanza Paper Company's Average Number of Accounts in Three Markets



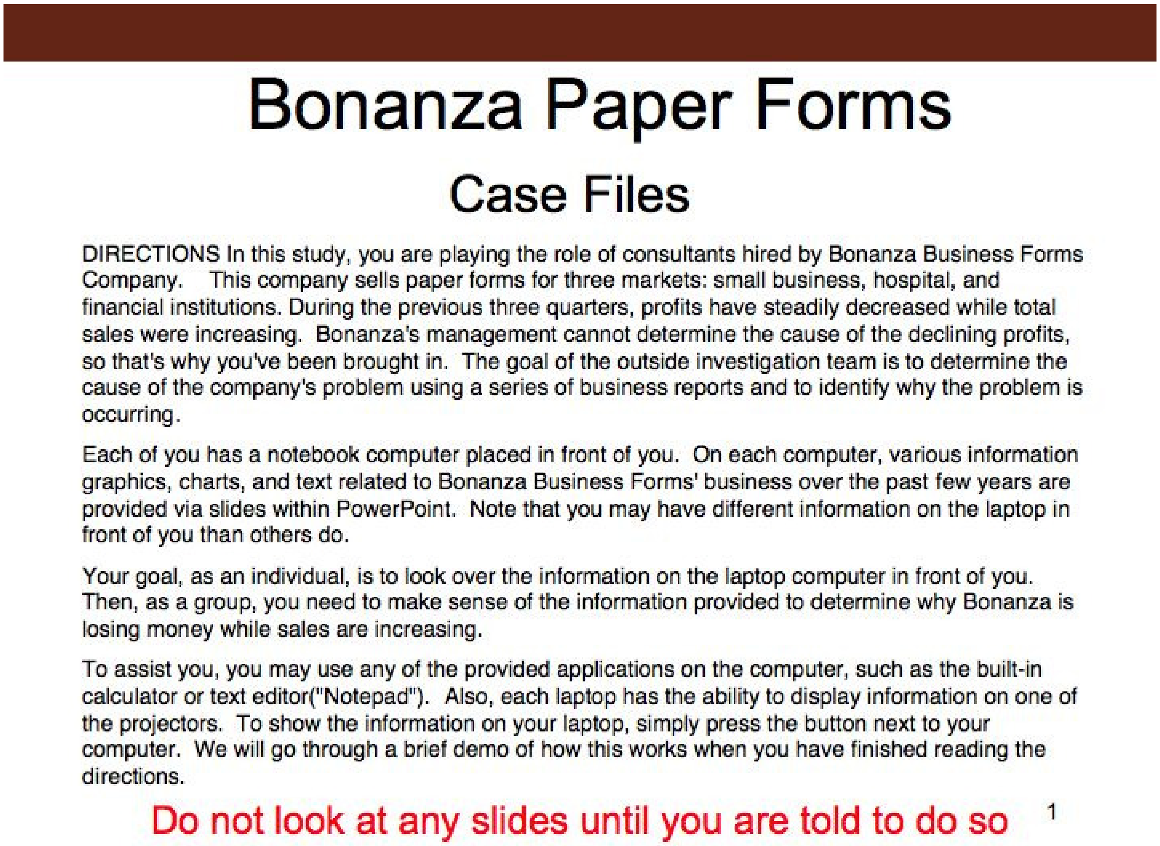
5

Fig 9: Number of Competitors in Market Areas



6

A.5 Participant 5’s Slides



Your Role:
Financial Analyst

For this meeting, you will play the role of a consultant who has researched the financial aspects of the markets that the company sells to. The following slides in this document provide data, charts, and figures related to this.

When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

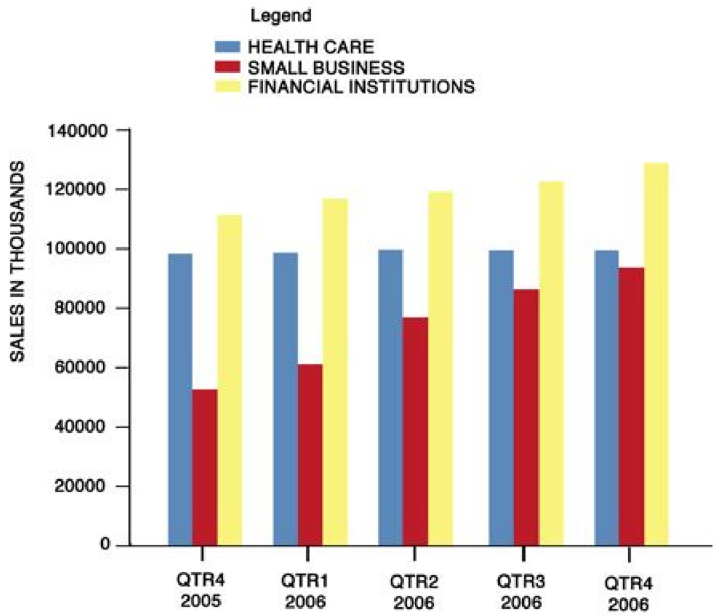
2

Internal Audit

- Research total industry sales
- Focus on the three markets Bonanza markets towards
  - Total Industry Sales vs
  - Quarterly Sales vs
  - Quarterly Profits

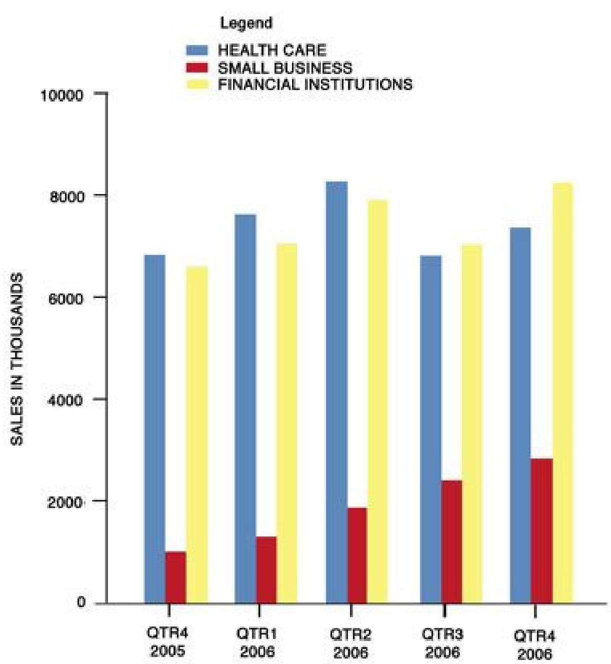
3

Fig 10: Total Industry Sales In Markets



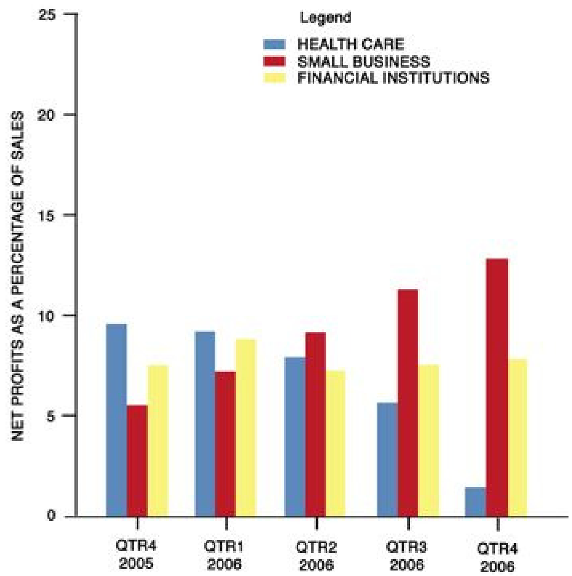
4

Fig 11: Quarterly Sales Dollars in Three Markets (in Thousands of Dollars)



5

Fig 12: Quarterly Net Profits as Percentage of Sales in Three Markets (in Percentages)



6

A.6 Participant 6's Slides

Bonanza Paper Forms

Case Files

DIRECTIONS In this study, you are playing the role of consultants hired by Bonanza Business Forms Company. This company sells paper forms for three markets: small business, hospital, and financial institutions. During the previous three quarters, profits have steadily decreased while total sales were increasing. Bonanza's management cannot determine the cause of the declining profits, so that's why you've been brought in. The goal of the outside investigation team is to determine the cause of the company's problem using a series of business reports and to identify why the problem is occurring.

Each of you has a notebook computer placed in front of you. On each computer, various information graphics, charts, and text related to Bonanza Business Forms' business over the past few years are provided via slides within PowerPoint. Note that you may have different information on the laptop in front of you than others do.

Your goal, as an individual, is to look over the information on the laptop computer in front of you. Then, as a group, you need to make sense of the information provided to determine why Bonanza is losing money while sales are increasing.

To assist you, you may use any of the provided applications on the computer, such as the built-in calculator or text editor("Notepad"). Also, each laptop has the ability to display information on one of the projectors. To show the information on your laptop, simply press the button next to your computer. We will go through a brief demo of how this works when you have finished reading the directions.

Do not look at any slides until you are told to do so

1

Your Role: Advertising Consultant

For this meeting, you will play the role of an advertising consultant. The following slides in this document provide data, charts, and figures related to the advertising and promotion costs associated with the company.

When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

2

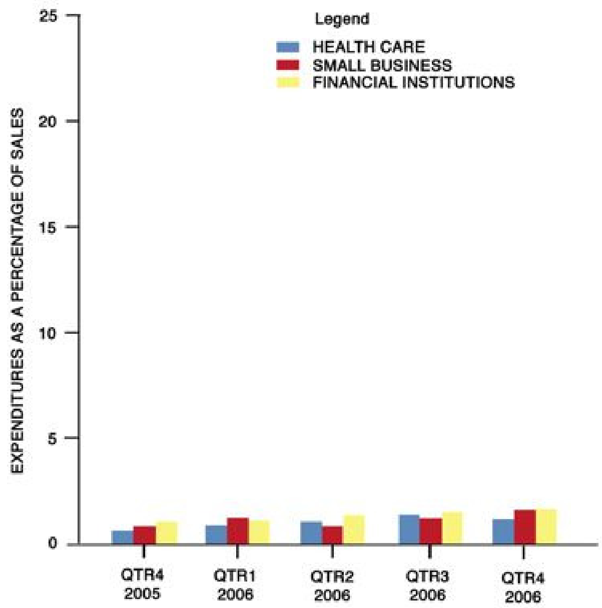
Advertising

- Advertises in health and financial community trade publications
- Send catalogs to small businesses
- Total advertising expenses are at the industry averages.
- Bonanza prides itself on maintaining quality in its products and relationships with customers.
  - As a result, Bonanza can charge prices at the industry average or slightly higher in some markets.

3

Advertising

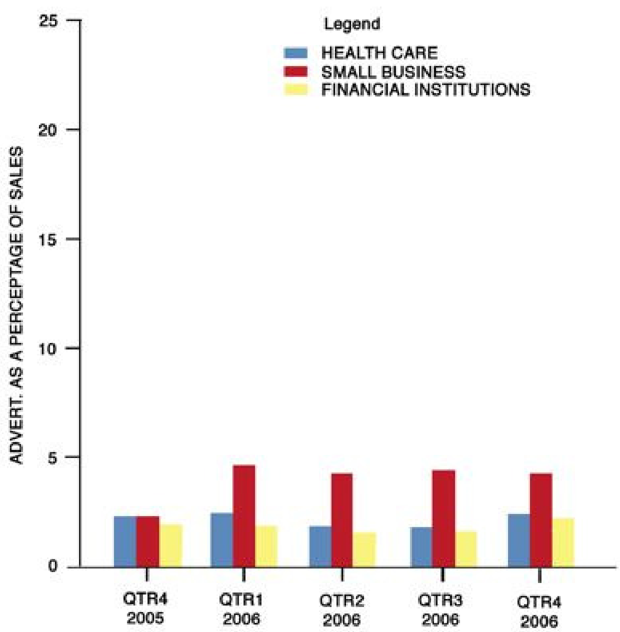
Quarterly Sales Promotion as a Percentage of Sales (in Percentages) (sales promotion includes price allowances and trade show displays)



4

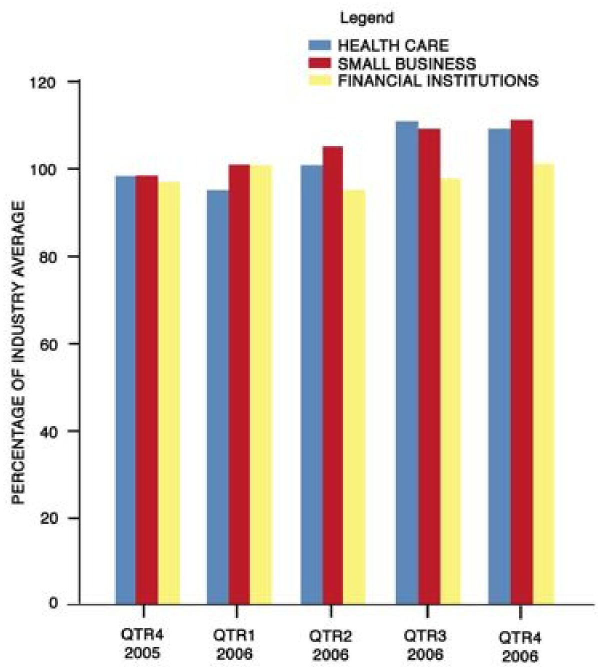
Advertising

Quarterly Advertising Expenditures as a Percentage of Sales (in Percentages)



5

Our Product Price as a Percentage of Industry Price Average in Three Markets



6

APPENDIX B

LABORATORY STUDY QUESTIONNAIRES

This appendix includes pre- and post-experimentation questionnaires administered to participants during the controlled evaluation.

Evaluating Display Placement in Meeting Environments
Demographic Information

Directions: Please complete this form to the best of your ability. If you have any questions, please ask the experimenter.

1. What is your gender? ☐ Male ☐ Female

2. What is your date of birth? ____ / ____ / ____ (mm/dd/yyyy)

3. What is your primary occupation? ________________________________

3B. If a student, what is your major? ________________________________

3C. If a student, list number of years of education. (12 = high school) ______________

4. Please list any management or business courses you have taken

5. Do you own a notebook (laptop) computer? ☐ Yes ☐ No

5A. On average, how often do you use your computer on a daily basis? ______________ (hours)

5B. On average, how often do you use your computer during class or a meeting? (never) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (frequently)
Please check one item on this scale

5C. What operating systems do you use on your notebook? If multiple, please rank them according to frequency of use. (i.e., 1st Windows XP, 2nd Red Hat Linux) to indicate you use Windows more than Linux

____

____

____

6. How familiar are you with Microsoft PowerPoint?	(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very) Please check one item on this scale
7. How many times have you used Microsoft PowerPoint while connected to a projector or large LCD display to share information with a group?	☐ Never ☐ 1-2 times ☐ 3-6 times ☐ 7 – 10 times ☐ more than 10 times
8. Do you have prior experiences working in a group or on a team? If yes, please indicate approximately how many groups you've worked with?	(in college) ☐ No ☐ Yes: ____________ (at a job) ☐ No ☐ Yes: ____________

For items 9-11, please indicate whether you agree or disagree with the statements provided.

9. On the average, working in groups is enjoyable	(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very) Please check one item on this scale
10. On the average, working by myself is enjoyable	(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very) Please check one item on this scale
11. On the average, I'd rather work by myself than in a group	(disagree) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (agree) Please check one item on this scale

12. Please list 3 words that you would describe *positive* group experiences you had:

13. Please list 3 words that you would describe a *negative* group experience you had:

14. Please describe how you've used technology in the past during a group project in the space below:

Evaluating Display Placement in Meeting Environments
Post Experiment Survey (Dual Display Conditions)

Directions: Please complete this form to the best of your ability. If you have any questions, please ask the experimenter.

1. After hearing and/or reading the initial introduction to the problem, was the correct solution immediately obvious to you?

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)
Please check one item on this scale

2. How realistic was the scenario to you? (Do you believe that this could be an example of an actual decision-making situation within an organization?)

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)
Please check one item on this scale

3. Please list three types of decisions that are typically made by a group within an organization (when the group is located in the same room at the same time)?

4. What did you use to share information with other group members?

5. What tool or skill did you wish you had to make the group decision-making process easier?

6. How well did you feel the group functioned collaboratively?

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)
Please check one item on this scale

7. Compared with your average group experiences, was this a better or worse experience?

(worse) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (better)
Please check one item on this scale

8. Do you feel that the group made a "good" decision?

(no) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (yes)

Please explain your answer:

9. Do you feel that the correct decision was made? ☐ Yes ☐ No

Please explain your answer.:

10. How satisfied were you with the process in which the group developed their solution? (not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please explain your answer:

11. How satisfied were you with the number of ideas the group came up with for the decline of profits (not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please explain your answer:

12. What factor, if any, would you say inhibited the generation of ideas within the group?

13. What factor, if any, would you say encouraged the generation of ideas within the group?

14. What are three thoughts that come to mind to describe the display-switching device?

15. Name two types of decision-making situations that you feel the switching device would be beneficial

____

____

16. Name two types of decision-making situations that you feel the switching device would not be useful

____

____

17. How distracting was having information displayed on two displays? (not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please Explain:

18. Overall, how useful was the display-switching device? (not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please Explain:

19. Overall, how user-friendly was the display-switching device? (not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

20. Please use the remaining space to write down any thoughts you have about the group experience, decision-making process, or the video-switch system.

Evaluating Display Placement in Meeting Environments
Post Experiment Survey

Directions: Please complete this form to the best of your ability. If you have any questions, please ask the experimenter.

1. After hearing and/or reading the initial introduction to the problem, was the correct solution immediately obvious to you?

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)
Please check one item on this scale

2. How realistic was the scenario to you? (Do you believe that this could be an example of an actual decision-making situation within an organization?)

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)
Please check one item on this scale

3. Please list three types of decisions that are typically made by a group within an organization (when the group is located in the same room at the same time)?

4. What did you use to share information with other group members?

5. What tool or skill did you wish you had to make the group decision-making process easier?

6. How well did you feel the group functioned collaboratively?

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)
Please check one item on this scale

7. Compared with your average group experiences, was this a better or worse experience?

(worse) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (better)
Please check one item on this scale

8. Do you feel that the group made a "good" decision?

(no) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (yes)

Please explain your answer:

9. Do you feel that the correct decision was made? ☐ Yes ☐ No

Please explain your answer.:

10. How satisfied were you with the process in which the group developed their solution? (not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please explain your answer:

11. How satisfied were you with the number of ideas the group came up with for the decline of profits (not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please explain your answer:

12. What factor, if any, would you say inhibited the generation of ideas within the group?

13. What factor, if any, would you say encouraged the generation of ideas within the group?

14. What are three thoughts that come to mind to describe the display-switching device?

15. Name two types of decision-making situations that you feel the switching device would be beneficial

16. Name two types of decision-making situations that you feel the switching device would not be useful

17. How distracting was having information displayed on the shared display?

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please Explain:

18. Overall, how useful was the display-switching device?

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

Please Explain:

19. Overall, how user-friendly was the display-switching device?

(not at all) ☐ ☐ ☐ ☐ ☐ ☐ ☐ (very)

20. Please use the remaining space to write down any thoughts you have about the group experience, decision-making process, or the video-switch system.

APPENDIX C
MIMOSA XML SCHEMA

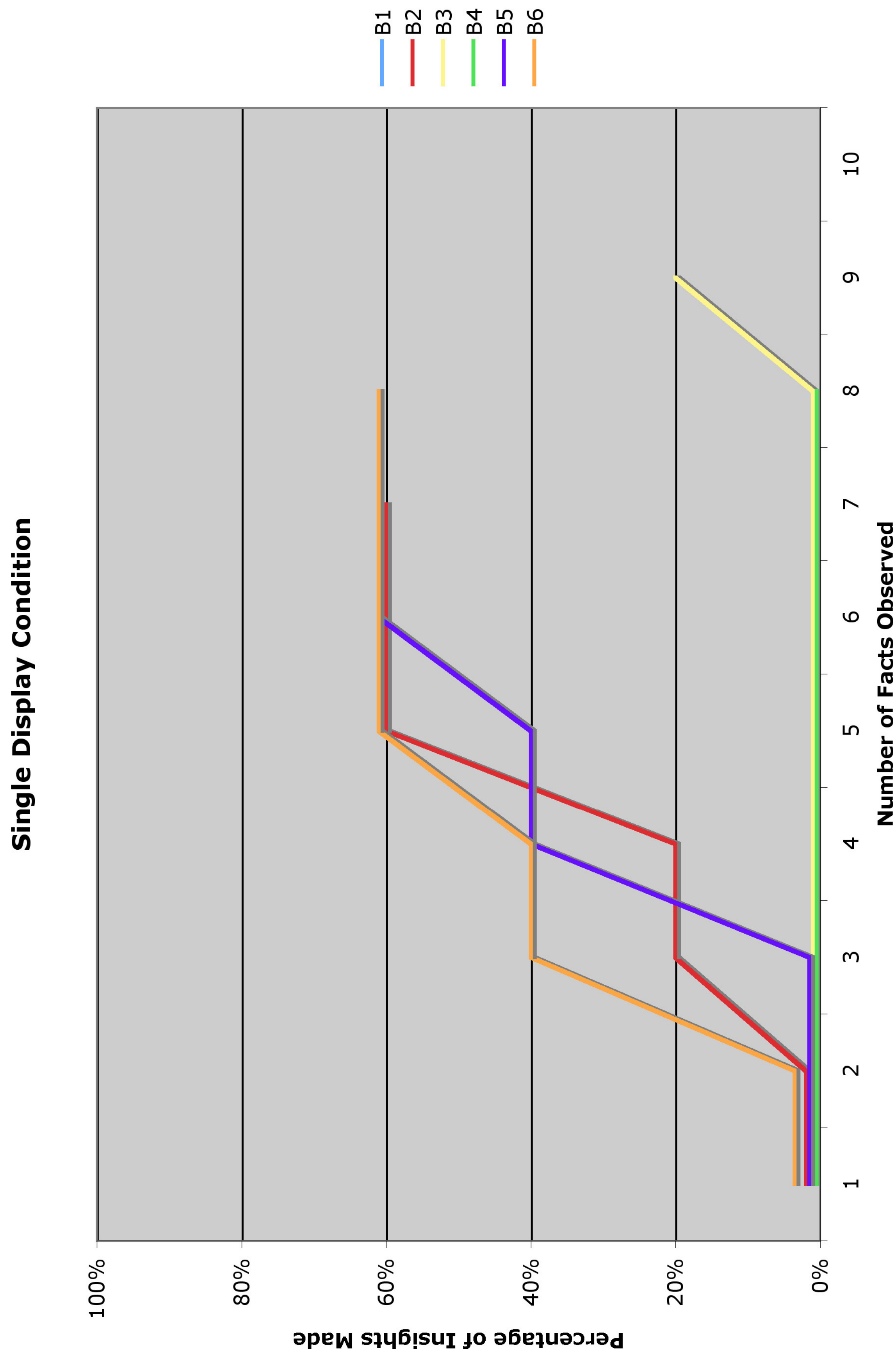
This appendix illustrates the XML schema used in the Mimosa visual analytic system, converting information from polled format.

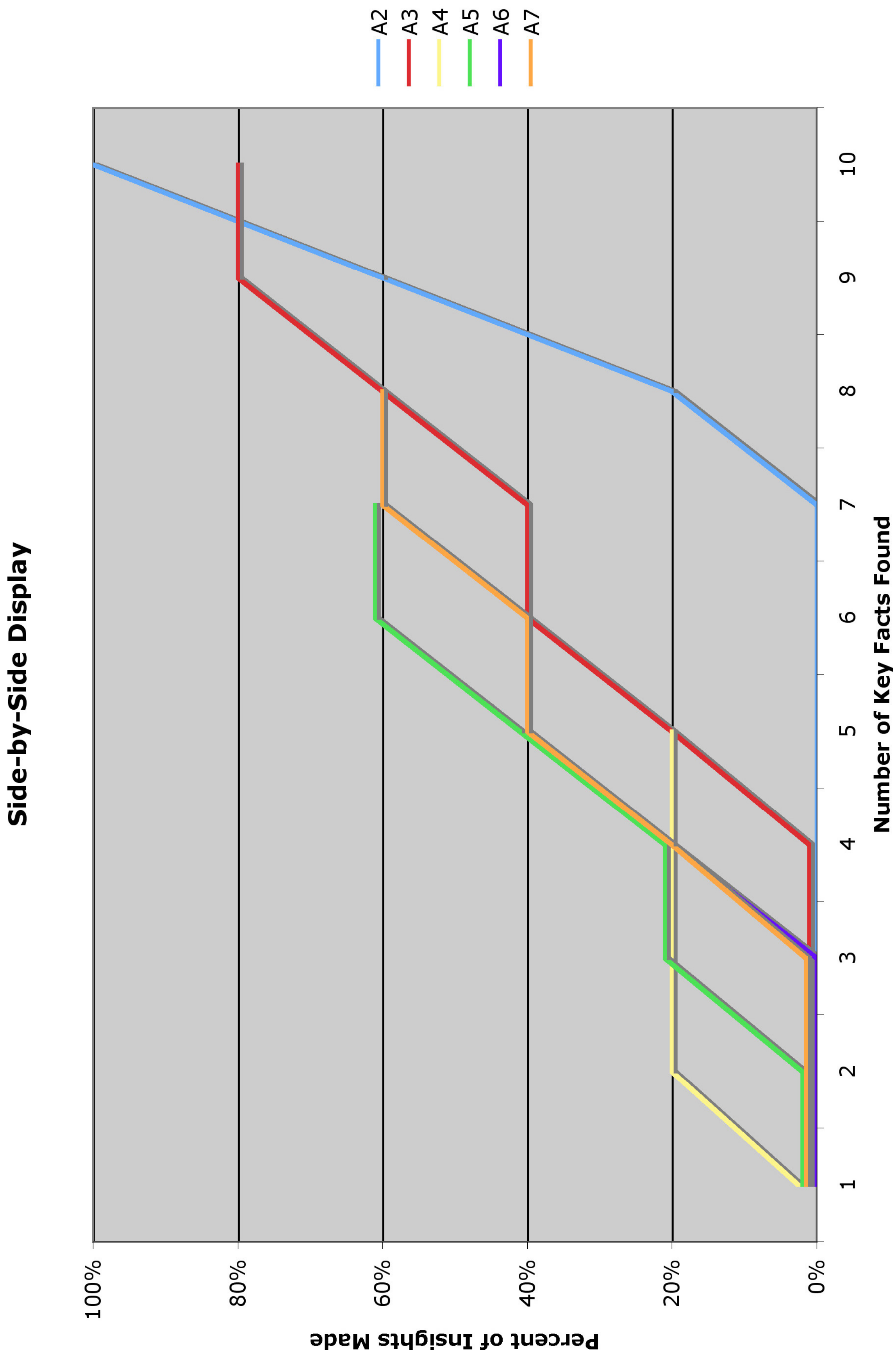
```
<?xml version="1.0" encoding="ISO-8859-1"?>

<meeting>
  <participants>
      <!-- list of participants referenced in the meeting -->

      <participant    <!-- description of single participant -->
       id="1"         <!-- unique identifier for this participant -->
       name="P1"      <!-- display name for the participant -->
      />
  </participants>

  <displays>
      <!-- list of displays used in the meeting -->

      <display                <!-- description of one display -->
        id="1"                <!-- unique identifier for display -->
        name="Display 1"      <!-- name of display -->
      />
  </displays>

  <slides>
      <!-- list of all slides used in meeting -->

      <slide                       <!-- details of a single slide -->
       id="p1s1"                   <!-- unique id for this slide -->
       participant="1"             <!-- id of owning participant -->
       slide="1"                   <!-- index of this slide -->
       image="slides/1_1.jpg"      <!-- path to the thumbnail -->
      />
  </slides>

  <activities>
      <!-- list of all activity occurrences in the meeting -->

     <activity                <!-- description of activity occurrence-->
       type="slide"           <!-- type (slide, gesture ,etc.) -->
       start="00:05:42"       <!-- when activity began-->
       end="00:05:51"         <!-- when activity ended, in secs since
                                   beginning of meeting -->
       display="2"            <!-- (optional) id of the display involved
                                   in this activity -->
       participant="1"        <!-- (optional) id of the participant
                                   involved in this activity -->
      slide="p1s5"           <!-- (optional) id of the slide involved
                                   in this activity -->

      />
 </activities>
</meeting>
```

APPENDIX D

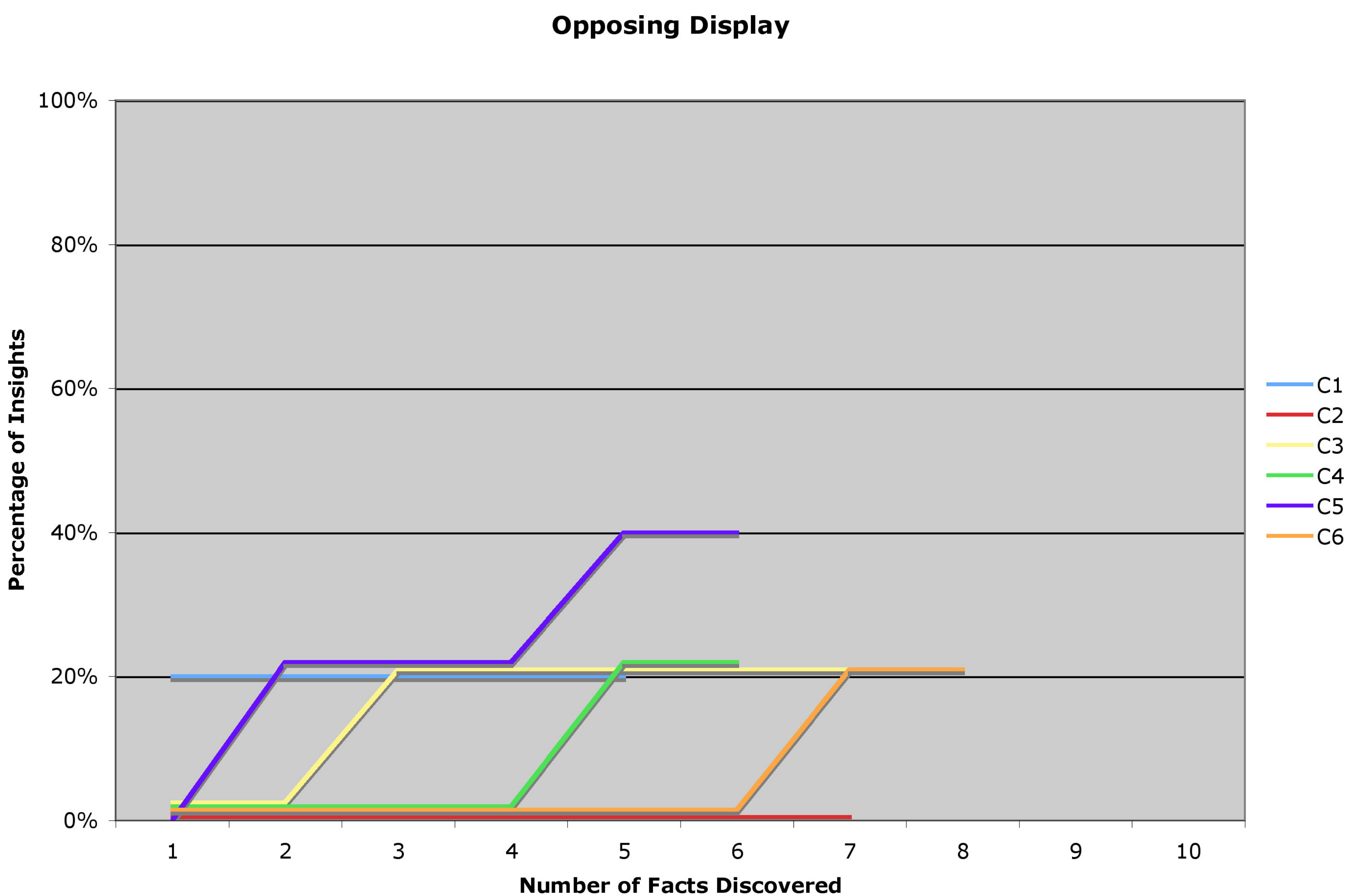
SUPPLEMENTAL GRAPHS

This appendix includes larger graphs of the percentage of insights made as a factor of the number of key facts observed, per group, per display condition.


Single Display Condition
Percentage of Insights Made
0%
20%
40%
60%
80%
100%
Number of Facts Observed
1
2
3
4
5
6
7
8
9
10
B1
B2
B3
B4
B5
B6



Side-by-Side Display
Percent of Insights Made
Number of Key Facts Found
0%
20%
40%
60%
80%
100%
1
2
3
4
5
6
7
8
9
10
A2
A3
A4
A5
A6
A7


Opposing Display
Percentage of Insights
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
Number of Facts Discovered
C1
C2
C3
C4
C5
C6

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